

No. 1

1928

THE JOURNAL

OF THE

IRON AND STEEL INSTITUTE

VOL. CXVII.

EDITED BY
GEORGE C. LLOYD
SECRETARY



PUBLISHED AT THE OFFICES OF THE INSTITUTE
28, VICTORIA STREET, LONDON, S.W. 1.

1928

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PREFACE.

THE present volume of the *Journal of the Iron and Steel Institute* contains the Presidential Address of Mr. Benjamin Talbot, the "Second Report on the Heterogeneity of Steel Ingots," prepared by a Committee of the Institute under the Chairmanship of Dr. W. H. Hatfield, and sixteen other papers, all presented at the Annual Meeting held in London, together with the discussion and correspondence thereon. It also contains a report of proceedings and speeches at the Annual Dinner held at the Connaught Rooms on May 3.

The usual notes on the progress of the home and foreign iron and steel industries as reported in the proceedings of Scientific and Technical Societies and in the technical press in Section II. have been entirely rearranged, and a new style of printing has been adopted; it is hoped that this innovation will make for easier reference to the abstracts. Section II. also contains notices of new books presented to the Institute, and a bibliography of the principal works dealing with the metallurgy of iron and steel and allied subjects which have appeared during the past six months. At the end is inserted a list of the British Standardised Steel Samples issued jointly by the Iron and Steel Institute and the National Physical Laboratory, showing where and on what terms the samples are available.

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July 31, 1928.



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ABBREVIATIONS USED IN TEXT.

Å	Ångström unit.	hr.	hour(s).
a.c.	alternating current(s).	in.	inch ; inches.
amp.	ampère(s).	in.-lb.	inch-pound(s).
amp.-hr.	ampère-hour(s).	K.	absolute temperature (scale).
atm.	atmosphere(s) (pressure).	kg.	kilogramme(s).
Bé.	Baumé (scale).	kg.-m.	kilogramme-metre(s).
B.H.P.	brake horse-power.	km.	kilometre(s).
B.O.T.	Board of Trade.	kva.	kilovolt-ampère(s).
B.th.u.	British thermal unit(s).	kw.	kilowatt(s).
B.T.U.	Board of Trade unit(s).	kw.-hr.	kilowatt-hour(s).
B.W.G.	Birmingham wire-gauge.	lb.	pound(s).
C.	centigrade (scale).	L.-F.	low-frequency.
cal.	calory ; calories.	m.	metre(s).
c.c.	cubic centimetre(s).	m.-amp.	milliampère(s).
c.d.	current density.	m.-volt	millivolt(s).
cg.	centigramme(s).	max.	maximum.
c.g.s.	centimetre - gramme - second unit(s).	mg.	milligramme(s).
cm.	centimetre(s).	min.	minimum ; minute(s).
coeff.	coefficient.	mm.	millimetre(s).
const.	constant(s).	m.m.f.	magnetomotive force(s).
c.p.	candle-power.	N.	normal (solution).
cu.	cubic.	N.T.P.	normal temperature and pressure.
cwt.	hundredweight(s).	O.-H.	open-hearth.
d.c.	direct current(s).	oz.	ounce(s).
dg.	decigramme(s).	p.d.	potential difference.
diam.	diameter(s).	R.	Réaumur (scale).
dm.	decimetre(s).	r.p.m.	revolutions per minute.
e.m.f.	electromotive force(s).	sec.	second(s).
F.	Fahrenheit (scale).	sp. gr.	specific gravity.
ft.	foot ; feet.	sq.	square.
ft.-lb.	foot-pound(s).	temp.	temperature.
gal.	gallon(s).	v.	volt(s).
gm.	gramme(s).	va.	volt-ampère(s).
H.-F.	high-frequency.	w.-hr.	watt-hour(s).
H-ion	hydrogen-ion.	yd.	yard(s).
H.P.	horse-power.	°	degree(s).
H.P.-hr.	horse-power-hour(s).		

SECTION I.

*MINUTES OF PROCEEDINGS
AND PAPERS OF
THE IRON AND STEEL INSTITUTE.*

ANNUAL MEETING

1928.

Editorial assistance has been given by A. E. CHATTIN, B.Sc. (Hons. Met.),
Assistant Secretary, in the preparation of this Section.

MINUTES OF PROCEEDINGS

AND

PAPERS AND DISCUSSIONS

AT THE

ANNUAL MEETING, 1928.

THE FIFTY-NINTH ANNUAL GENERAL MEETING OF THE IRON AND STEEL INSTITUTE was held at the Institution of Civil Engineers, Great George Street, Westminster, on Thursday and Friday, May 3 and 4, 1928. Mr. F. W. HARBORD, C.B.E., the retiring President, took the Chair, and was succeeded by Mr. B. TALBOT.

The Minutes of the last General Meeting were taken as read and confirmed.

SCRUTINEERS.

Mr. E. C. EVANS (London) and Mr. S. A. MAIN (Sheffield) were appointed scrutineers of the ballot for the examination of the voting papers, and they subsequently announced that the following eighty-four candidates for membership and four candidates for associateship had been duly elected :

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Takebayashi, Seiichi .	169 Northumberland Road, Sheffield	U. Ohata, T. G. Elliot, S. A. Main.
Tennent, James . .	Whifflet Foundry, Coatbridge	H. B. Toy, J. L. Smith, S. V. Toy.
Terrile, Alan Peter .	361 East End Avenue, Beaver, Pa., U.S.A.	O. L. Pringle, W. P. Benter, F. H. Allison, jun.
Thomas, Kenneth Treherne	Oughtrington Hall, Lymm, Cheshire	C. T. Thomas, J. Davies, T. O. Lewis.
Thomson, David, B.Sc., M.B.E.	39 Carsick Hill Road, Sandygate, Sheffield	F. Atkinson, J. H. G. Monypenny, M. R. Mainprice.
Villa Onaindia, Jose Ignacio	Avenida de Basagoiti 5, Neguri, Vizcaya, Spain	E. Coste, J. Chirapozu, V. Balanzategui.
Wood, George . .	21 Vainor Road, Hillsborough, Sheffield	J. Ward, Sir Wm. Ellis, G.B.E., M. R. Mainprice.
Ybarra, Fernando J. de, B.A. (Cantab.)	Arriluce, Algorta, Vizcaya, Spain	El Conde de Zubiria, A. de Churruca, Marqués de Arriluce de Ybarra.
Zubiria Somonte, Manuel de	Elcano 22 bº, Bilbao, Spain	El Conde de Zubiria, J. Roure, L. Barreiro.

ASSOCIATES.

Baker, Arthur Jesse .	98 Beresford Avenue, Foleshill, Coventry	E. M. Boote, F. H. Hurren, H. H. Harley.
Frith, Percy Herbert .	48 Blayton Road, Pitsmoor, Sheffield	J. H. S. Dickenson, G. E. Howarth, J. Swan.
Hall, Douglas . .	151 Rock Street, Pitsmoor, Sheffield	W. H. Hatfield, J. A. Clements, C. H. Desch.
Smallman-Tew, Richard	Royal School of Mines, South Kensington, S.W. 7	H. C. H. Carpenter, W. H. Merrett, W. H. Dearden.

PRESENTATION OF ANNUAL REPORT AND STATEMENT OF
ACCOUNTS FOR 1927.

The PRESIDENT said the Annual Report of Council had been circulated and, with the permission of the members, he proposed that it be taken as read. He then asked the Honorary Treasurer to submit his report on the Accounts.

Professor H. C. H. CARPENTER, F.R.S. (Hon. Treasurer), in presenting the Balance Sheet and Statement of Accounts for 1927, said he had unfortunately to call attention, as he did in the previous year, to the tendency evident in the past three years for the expenditure to rise while the income remained stationary, or even tended to fall slightly. It would be found that the Income and Expenditure Account for the year ended December 31, 1927, showed a deficit amounting to not less than £879, which revealed a serious position for the Institute. It was attributable to various causes, but mainly to the increased expenditure on the publication of the Journal containing the papers, discussions, and abstracts, the total cost of which last year rose to £2810, or about £700 in excess of the normal expenditure. Actually nearly the whole of that increase was caused by the first volume for the year. Normally the Institute published about 400 pages of papers and discussions, but the volume in question contained about 700 pages, so that the Institute had given members not only extremely good value, but too good value for the year in question. That was responsible for about £660 out of the total of £879. That item was well within the control of the Council ; it would be necessary to ration the members, and the Council had decided to do so with reference to the size of the Journal. It was satisfactory that the largest item causing the deficit was absolutely within the control of the Council.

Besides that heavy charge the whole financial position of the Institute was seriously affected by the fact that the Inland Revenue Commissioners had, during the past year, disallowed the usual claim for refund of income-tax on the General and Special Funds of the Institute, and that was responsible for a loss of £134. The Institute in that respect was in the same position as all other scientific and technical societies. Two appeals were being heard

in the Courts at the present moment, and if they were allowed the Institute would recover that money, but for the present it had to be reckoned as a loss. For the time being the deficit could be met by drawing upon the accumulated funds of the Institute, but obviously it would not be possible to repeat that operation frequently in the future.

Actually the item which caused the Council the greatest concern was the smallest one financially—it was less than £100—namely, the Institute was down about £75 on the year in subscriptions. He had no doubt that that was simply another instance of what had been going on for the last six years, namely, that the membership of the Institute was declining. He thought the members ought to know that on December 31 last year the net membership of the Institute had declined 245 compared with December 31, 1921, a diminution of 11 per cent. That matter had caused the Council great concern, and as a result they had set up seven Committees, one in each of the great iron and steel producing districts of the country, each one presided over by a Member of Council, and those Committees had been asked to make suggestions as to how new members could be obtained. He thought there was little doubt that those Committees would be able to help very much, particularly in bringing forward the names of new candidates—and he hoped young candidates—for membership of the Institute. Although the present position was undoubtedly unsatisfactory, he thought it was well within the power of the Institute to recover, and he hoped before long they would be able to resume the increased membership which had hitherto been the case. A number of causes contributed to the present position, which he did not desire to go into on the present occasion; but he thought it would be realised that the drop in numbers had been largely connected with the very difficult time through which the steel trade of the country had been passing.

The PRESIDENT said he desired formally to propose the adoption of the Annual Report and Statement of Accounts for 1927, and as the motion did not require a seconder, he would put it immediately to the meeting.

The resolution was then put and carried unanimously.

REPORT OF COUNCIL.

THE Council of the Iron and Steel Institute have much pleasure in submitting for the approval of the members at this, the Fifty-Ninth Annual General Meeting, their Report on the proceedings and work of the Institute during the year 1927.

ROLL OF THE INSTITUTE.

During the past year sixty-seven new members and nine associates were elected; ten associates were transferred to membership, and twelve members were reinstated. Fifty-three members and one associate resigned their membership during the year, and the names of thirty members were removed from the register owing to the non-payment of their subscriptions. The total membership of the Institute on the register on December 31, 1927, was accordingly as follows:

Patron	1
Honorary Members	5
Life Members	81
Ordinary Members	1879
Associates	17
<hr/>	
Total	1983

The Council deeply regret to have had to record the deaths of the following twenty-nine members of the Institute which occurred during the year:

Bowden, G. R. H. (St. Albans)	October 10.
Camp, J. M. (Pittsburgh, U.S.A.)	October 24.
Campionnet, P. (Gueugnon, France) . . . . .	...
Cawley, G. (Sutton)	March 3.
Cohen, B. (London) . . . . .	...
Davies, <i>Sir</i> John C., C.B.E. (Newport, Mon.)	August 29.
Davis, E. Prosser (Ilkeston)	January 31.
Dyson, W. H. (Guildford)	November 12.
Ford, E. L. (Youngstown, U.S.A.)	July 4.
Forsyth, R. (Chicago, U.S.A.)	September 11.
Gary, <i>Judge</i> E. H. (New York) (Hon. Vice-President)	August 15.
Haslam, <i>Sir</i> A. S. (Derby)	January 13.

Humphryes, J. H. (London)	May 22.
Jack, A. G. M. (Sheffield)	August.
Kearns, H. W. (Brooklands, Cheshire)	January 28.
Kemnal, <i>Sir</i> J. H. R. (London)	February 8.
Kerr, James (Motherwell)	...
Milius, J. (Paris)	...
Patchett, J. (Hadley, Shropshire)	July 30.
Pease, R. (Durham)	July 12.
Rand, C. F. (New York) (Hon. Member)	June 21.
Ryland, F. C. (Birmingham)	March 6.
Scott, G. L. (London)	January 16.
Smith, S. (Sheffield)	July 28.
Spencer, A. M. (Sheffield).	June.
Steer, E. (Newport, Mon.) (Hon. Vice-President)	October 29.
Stein, J. G. (Polmont, Stirlingshire)	...
Trasenster, E. (Liège)	August 1.
Wille, H. V. (Philadelphia, U.S.A.)	November 29.

The deaths of the following five members took place prior to 1927, but were not reported to the Council until that year :

Abel, W. F. (Ohio, U.S.A.)	December 8, 1926.
Odelberg, G. (Djursholm, Sweden)	October 1925.
Raine, G. (Newcastle-on-Tyne)	December 24, 1926.
Sanderson, O. (Hull)	December 25, 1926.
Uchermann, A. W. (Kongsberg, Norway)	June 1926.

The Council specially wish to place on record their sense of the great loss to the Institute incurred through the deaths of the following : Mr. Edward Steer, who had served on the Council since 1910 and was Chairman of the Reception and Executive Committee of the Cardiff Meeting in 1920 (Mr. Steer was elected a member of the Institute in 1873) ; Judge Elbert H. Gary, Chairman of the U.S. Steel Corporation and President of the American Iron and Steel Institute, who was elected an Hon. Vice-President of the Institute in 1922 ; and Mr. Charles F. Rand (New York), who was made an Honorary Member in 1921. Obituary notices of these and of other members deceased were published in the last volume of the Journal.

ELECTION OF HONORARY MEMBER.

In the past year Mr. J. T. Milton, late Chief Engineer Surveyor, now Consultant Engineer to Lloyd's Register of Shipping, has been elected an Honorary Member. He was originally elected a member of the Institute in 1891.

HONOURS CONFERRED ON MEMBERS.

The Council tender their most hearty congratulations to several members of the Institute upon whom appointments of honour and distinction have been recently conferred.

Mr. H. Mechan has been created a Knight Bachelor. Mr. Leon Greiner has been created by His Majesty the King of the Belgians Officier de l'Ordre de Leopold, also Chevalier de la Couronne de Belgique. Further, Her Majesty the Queen of Holland has been pleased to create Mr. L. Greiner Officier de l'Ordre d'Orange-Nassau. Sir Arthur Balfour has been made a Commander of the Order of Danebrog by His Majesty the King of Denmark. Mr. H. Spence Thomas has been appointed a Knight Commander of Nicham Iftikhar. The President of the French Republic has been pleased to confer upon Professor H. Le Chatelier the Grand Croix de la Légion d'Honneur, and upon Mr. C. Vanzetti the Insignia of Officier de la Légion d'Honneur. Mr. F. L. Warren has been appointed a Member of the Order of the British Empire, and Captain L. D. Whitehead has been appointed High Sheriff of the County of Monmouth.

Sir Robert Hadfield, Bt., F.R.S., has had bestowed upon him by Oxford University the Degree of Doctor of Science *honoris causâ*, and he has also been elected an Honorary Life Member of the Institution of Mechanical Engineers. Mr. F. W. Harbord, C.B.E., Sir Frederick Mills, Bt., and Sir Peter Rylands have been elected Honorary Members of the American Iron and Steel Institute. Sir William Ellis, G.B.E., D.Eng., has been appointed President of the Engineering Section of the British Association Meeting (Glasgow, 1928). Professor H. Le Chatelier has been elected an Honorary Member of the American Society of Mechanical Engineers.

Sir William Larke, K.B.E., has been appointed a Member of the Advisory Council to the Committee of the Privy Council for Scientific and Industrial Research; Sir Arthur Duckham, K.C.B., Mr. M. Mannaberg, and Mr. C. H. Merz have been appointed Members of the National Fuel and Power Committee appointed by the President of the Board of Trade. Mr. B. Talbot was elected President, and Mr. E. J. Fox Vice-President, of the National Federation of Iron and Steel Manufacturers. Mr. P. W. Lee has been elected Master Cutler of Sheffield, Professor H. Louis has been elected President of the Institution of Mining Engineers, and Dr. W. Rosenhain, F.R.S., has been elected President of the Institute of Metals. Mr. C. M. Schwab

has succeeded the late Judge E. H. Gary as President of the American Iron and Steel Institute, and has also accepted election as Honorary Vice-President of the Iron and Steel Institute. Mr. G. Hedley was elected President, and Mr. B. Walmsley Vice-President, of the Cleveland Ironmasters' Association. Professor F. C. Thompson has been elected President of the Institution of Welding Engineers.

Professor C. A. Edwards was appointed Principal of University College, Swansea, in succession to Dr. Sibley, and Dr. A. L. Norbury has been appointed Senior Metallurgist to the British Cast Iron Research Association.

Dr. Zay Jeffries has been awarded the James Douglas Medal of the American Institute of Mining and Metallurgical Engineers, and Major R. A. Bull has been awarded the Joseph S. Seaman Gold Medal by the American Foundrymen's Association. To Mr. C. M. Schwab has been awarded the Medal of the American Arbitration Association in appreciation of his distinguished services in the cause of industrial peace. Mr. E. M. Boote has been presented with the Birmingham Metallurgical Society's Medal.

FINANCE.

The Statement of Accounts for the year 1927, which has been duly audited and certified by Messrs. W. B. Keen & Co., the Institute auditors, accompanies this Report, and is presented by Professor H. C. H. Carpenter, F.R.S., the Honorary Treasurer, for the approval of the meeting.

The income for the year under review, apart from that of the Carnegie Scholarship Fund and of the Special Purposes Fund, was £7831, and the expenditure was £8710. The comparative figures of the income and expenditure for the last five years are shown herewith :

	Income.	Expenditure.
	£	£
1922	7964	7939
1923	8095	8012
1924	8068	7568
1925	7952	8084
1926	8136	8160

The adverse balance of £879 in the accounts for the year 1927 is chiefly due to the increased cost of the publications of the Institute.

MEETINGS.

The Annual Meeting of the Institute was held in the Hall of the Institution of Civil Engineers, by kind permission of the Council of that body, on Thursday and Friday, May 5 and 6, 1927, the chair being taken by the President, Mr. Frank W. Harbord, C.B.E.

The Annual Dinner was held at the Connaught Rooms on the evening of Thursday, May 5, and was attended by some 350 members and guests. Speeches were delivered by Mr. H. B. Betterton, C.B.E., M.P. (Parliamentary Secretary to the Ministry of Labour, and present on behalf of the Right Hon. Sir A. Steel-Maitland, the Minister of Labour), Sir W. Peter Rylands (Past-President), Mr. John Craig, C.B.E. (Member of Council), the Right Hon. John Hodge, and the President.

The Autumn Meeting of the Institute was held, by the kind invitation of the West of Scotland Iron and Steel Institute, at Glasgow, on September 20 to 22, and was attended by about 450 members and their ladies. On Tuesday, September 20, the members and their ladies were entertained to luncheon by the Reception Committee, while on the evening of the same day a Reception was held in the City Chambers by the Right Hon. Lord Provost and Corporation of the City of Glasgow. On Wednesday, September 21, the members were entertained to luncheon at the Central Hotel by the President and Directors of the Glasgow Chamber of Commerce, and in the evening all the members and their ladies were entertained at dinner at the same hotel by the General Reception Committee. On Thursday, September 22, Mr. John Craig, C.B.E., the President of the West of Scotland Iron and Steel Institute, again entertained the members and their ladies to luncheon, and in the evening a supper-dance was held in the Central Hotel by invitation of the Reception Committee. On the afternoons of these three days visits were made by the members to thirteen works in the neighbourhood of Glasgow, where they saw much of interest, and were most hospitably entertained by the directors and members of the various staffs, while separate arrangements, including visits to places of interest in and about Glasgow, as well as Edinburgh and Callander, were made for the ladies. On Friday, the 23rd, the whole day was devoted to an excursion on the Firth of Clyde on the T.S.S. *King George V*.

The success of the meeting was very largely due to the careful forethought and excellent arrangements of the Local Reception Committee, and the results of their labours were very much appreciated.

BESSEMER MEDALS.

For the year 1927 two Bessemer Gold Medals were awarded by the Council, one to Mr. A. Wahlberg, for his eminent services in fostering the advancement of the metallurgy of iron and steel on the more practical side, and the other to Professor Carl Benedicks for similar services rendered by his valuable researches in physical-chemical metallurgy.

PAPERS.

Thirty-one papers were contributed to the Proceedings of the Institute during the year. Of these papers, sixteen were presented at the Annual Meeting and fifteen at the Glasgow Meeting. The following is a complete list :

- ANDREW, J. H., and H. A. DICKIE—"The Ac_1 Range in Special Steels."
- ANDREW, J. H., M. S. FISHER, and J. M. ROBERTSON—"The Properties of some Nickel-Chromium-Molybdenum Steels."
- ATKINS, E. A.—"The Drawing of Steel Wire and its Relation to Qualities of Steel."
- BENEDICKS, C., and H. LÖFQUIST—"Theory of the Growth of Cast Iron Repeatedly Heated."
- BONE, W. A., L. REEVE, and H. E. SAUNDERS—"An Experimental Inquiry into the Interactions of Gases and Ore in the Blast-Furnace."
- CAMPBELL, D. F.—"High-Frequency Induction Melting."
- DICKIE, H. A.—"Magnetic and other Changes concerned in the Temper-Brittleness of Nickel-Chromium Steels."
- EDWARDS, C. A., and J. C. JONES—"The Influence of Annealing Temperature on the Properties of Mild Steel Sheets."
- EDWARDS, C. A., and K. KUWADA—"The Influence of Cold-Rolling and Subsequent Annealing on the Hardness of Mild Steel."
- EVEREST, A. B., T. H. TURNER, and D. HANSON—"The Influence of Nickel and Silicon on an Iron-Carbon Alloy."
- GILL, C. S.—"The Effect of Varying Ash in the Coke on Blast-Furnace Working."
- HADFIELD, Sir ROBERT—"The Metal Manganese and its Properties; also Ores, and the Production of Ferro-Manganese and its History."
- HADFIELD, Sir ROBERT—"Alloys of Iron and Manganese containing Low Carbon."
- HANSON, D.—"The Constitution of Silicon-Carbon-Iron Alloys, and a New Theory of the Cast Irons."
- HATFIELD, W. H.—"Heat-Resisting Steels."
- HERBERT, E. G.—"The Work-Hardening of Steel by Abrasion."
- HONDA, K., and K. TAKAHASI—"A Further Investigation of the Indentation Hardness of Metals."

- HONDA, K., and K. TAKAHASHI—"On the Quantitative Measurement of the Cutting Power of Cutlery."
- LEWIS, E. H.—"The Use of Silica Gel as a Medium for Drying Blast."
- MATSUSHITA, T., and K. NAGASAWA—"The Mechanism of Tempering of Steels."
- MATSUSHITA, T., and K. NAGASAWA—"The Phenomenon of Temper-Hardening in Steels."
- ROBINSON, T. W.—"The Economic and Social Development of the American Iron and Steel Industry."
- ROSENHAIN, W.—"Alloys of Iron Research." "Part V.—Preparation of Pure Chromium," by F. Adcock. "Part VI.—Preparation of Pure Manganese," by Marie L. V. Gayler. "Part VII.—Preparation of High Purity Silicon," by N. P. Tucker. "Part VIII.—The Constitution of Alloys of Iron and Phosphorus," by J. L. Haughton.
- ROSENHAIN, W., and D. HANSON—"The Behaviour of Mild Steel under Prolonged Stress at 300° C."
- SEIGLE, J.—"Some Aspects of the Technical and Economic Conditions of the Heavy Metallurgical Industry of the East of France, with Particular Reference to the Utilisation of Gases and Motive Power."
- SMITH, J. H., and F. V. WARNOCK—"A Testing Machine for Repeated Impact, and a Preliminary Investigation on the Effects of Repeated Impact on Lowmoor Iron."
- SWINDEN, T., and G. R. BOLSOVER—"Some Notes on Cold-Rolled Strip Steel."
- TAMURA, S.—"Notes on Pseudo-Twinning in Ferrite, and on the Solubility of Carbon in Alpha-Iron at the A₁ Point."
- WHITELEY, J. H.—"The Solution of Carbon in α -Iron and its Precipitation."
- WÜST, F.—"A Contribution to the Theory of the Blast-Furnace Process."
- YANESKE, B.—"The Manufacture of Steel in India by the Duplex Process."

Volume XVI. of the Carnegie Scholarship Memoirs was published in 1927, and contained the following reports :

- ADAMSON, C. H., and G. S. BELL—"Transverse Tests on Cast Iron."
- BRAMLEY, A., and G. LAWTON—"The Gaseous Cementation of Iron and Steel. Part III.—The Influence of Hydrocarbons on the Carburisation of Iron and Steel."
- FELL, E. W.—"Strain in Steel."
- NEWTON FRIEND, J.—"Third Report on the Relative Corrodibilities of Various Commercial Forms of Iron and Steel."
- PFEIL, L. B.—"The Effect of Cold-Work on the Structure and Hardness of Single Iron Crystals and the Changes Produced by Subsequent Annealing."

PUBLICATIONS.

The usual two volumes of the Journal, containing together 1800 pages, a volume of the Carnegie Scholarship Memoirs of 210 pages, and a List of Members (168 pages), have been published during the year.

ANDREW CARNEGIE RESEARCH SCHOLARSHIPS.

On the recommendation of the Carnegie Research Committee, grants were made by the Council during the year to the following candidates :

B. S. SMITH (Sheffield), £100, to assist in carrying out research work under the direction of Professor C. H. Desch at Sheffield University on behalf of the Heterogeneity Committee, the subject being the viscosity of molten steel.

DAVID BINNIE (Glasgow), £100, to assist in carrying out research work under the direction of Professor J. H. Andrew at the Royal Technical College, Glasgow, on behalf of the Heterogeneity Committee, the main subjects being the determination of the liquidus and solidus of carbon and alloy steels, and a study of reactions of sulphides in liquid and solid steels.

R. M. COLLES (London), £100, to carry out a research on the transfer of heat in heat exchangers used in the iron and steel industry.

EDWIN MORGAN (Birmingham), £100, to carry out a research on the electrical and dilatometric properties of cast irons at temperatures up to 1000° C.

T. F. PEARSON (Dudley, Worcs.), £100, to carry out a research on graphitisation in iron-carbon alloys.

E. VALENTA (Skoda Works, Ltd., Czecho-Slovakia), £100, to study heat- and acid-resisting cast irons containing chromium-silicon-aluminium.

G. R. WOODVINE (Shrewsbury), £100, to study the influence of nickel upon the wearing properties of case-hardening steel.

CARNEGIE GOLD MEDALS.

The award of the Carnegie Gold Medal, in abeyance since 1914, was reinstated by the Council in 1927. In doing so, it was decided to take into consideration all reports published during the last twelve years by research workers under thirty-six years of age at the time of making the original grant. Three reports were selected for the award. The first was that by Mr. J. H. Whiteley (Saltburn-by-the-Sea) on "The Eggertz Test for Combined Carbon in Steel" (1917); the second was by Mr. Frank Bainbridge (Skinningrove) on "The Effect of Fluorspar Additions on the Phosphates in Basic Slag" (1920); and the third was that by Mr. A. L. Curtis (Chatteris, Camb.) on "Steel Moulding Sands and their Behaviour under High Temperatures" (1925). At the

Glasgow meeting the President (Mr. Harbord) presented to each of these research workers the Carnegie Gold Medal.

WILLIAMS PRIZE.

In the year under review the scheme under which the Williams Prize Fund is administered came into operation for the first time. Two of the papers by authors qualified for consideration appeared to the Council to be worthy of an award, and accordingly it was decided to divide the prize between them as follows : to Mr. E. A. Atkins (50 guineas) for his paper on "The Drawing of Steel Wire and its Relation to Qualities of Steel," presented at the Annual Meeting ; and to Mr. C. S. Gill (30 guineas) for his paper on "The Effect of Varying Ash in the Coke on Blast-Furnace Working," presented at the Autumn Meeting.

LIBRARY.

During the year 1927, 28 new text-books have been presented to the Library, and notices of all these works have been published in the Journal in the usual place. The Council take the opportunity to extend their sincere thanks to the donors. Besides these, over 400 pamphlets have been received, and 70 books have been acquired by purchase. Inasmuch as the keeping of the Library fully up to date to meet the increasing demands made upon its resources involves an ever-growing expense, the presentation of books, and especially of new books, is most gratefully appreciated. The Library service now constitutes one of the most useful branches of the Institute's activities, and it is gratifying to know that its sphere of usefulness continues to extend, and that members are availing themselves more and more of its organisation for purposes of research and inquiry. The practice of sending out books on loan is increasingly taken advantage of, the number of publications borrowed from the Library in 1927 having been 620. The arrangements for dealing promptly with inquiries on any technical subject continue to work satisfactorily.

TECHNICAL COMMITTEES.

During 1927 four of the Technical Committees appointed by the Council in 1917 were discharged. Committee No. 5 (Metallography, Chemistry, and Physics) and the Committee on the Heterogeneity of

Steel Ingots have been retained ; while the four that have been discharged have been replaced by the following four new Committees :

Committee No. 1—Coke-Oven Plant and Practice.

Committee No. 2—Blast-Furnace Plant and Practice.

Committee No. 3—Steel Furnace Plant and Production of Steel Ingots by all Processes.

Committee No. 4—Rolling-Mill Plant and Practice.

The four new Committees have already held several sessions, and are at present fully occupied with matters coming within their scope. The Committee on the Heterogeneity of Steel Ingots, whose First Report was published in 1926, has been actively pursuing its investigations, and its Second Report will be published in Journal No. I., 1928.

THE WORSHIPFUL COMPANY OF BLACKSMITHS.

In accordance with the understanding with the Wardens of the Company of Blacksmiths, applications for nomination for admission to the Company were invited, and Mr. H. Allcard of Sheffield has been recommended by the Council for admission to the Company.

APPOINTMENT OF REPRESENTATIVES.

The President continues to represent the Institute on the General Committee of the Royal Society for administering Government Grants for Scientific Investigations. Sir Robert Hadfield, Bt., and Mr. F. W. Harbord, C.B.E., represent the Institute on the Board of the National Physical Laboratory, and Sir Hugh Bell, Bt., performs a like office on the Board of Governors of the Imperial College of Science and Technology.

The Institute representatives on the Main Committee of the British Engineering Standards Association have been Mr. M. Mannaberg, Mr. B. Talbot, and Sir Frederick Mills, Bt. ; on the Sectional Committee of the B.E.S.A. for the Standardisation of Galvanised Sheets, Mr. C. Dorman ; on the Sub-Committee for Cast Iron, working under the direction of the Sectional Aircraft Committee, Mr. H. J. Yates and Dr. W. H. Hatfield ; on the Sectional Committee on Cast Iron, Mr. H. B. Toy ; on the Technical Committees of Motor Industries, Mr. J. H. S. Dickenson ; and on the Sectional Committee for Chemical Engineering, Mr. F. W. Harbord, C.B.E.

Mr. F. Clements is the Institute representative on Panel D, on Gas-Producer Trials, of the Institution of Civil Engineers. Professor
1928—i. c

T. Turner is the Institute's Delegate to the British Cast Iron Research Association. Sir Robert A. Hadfield and Mr. Harbord represent the Institute on the Council of the British Refractories Research Association, and Mr. Harbord represents the Institute on the Alloys of Iron Research Committee, and on the Advisory Board of the Royal School of Mines. On the Committee on the Improvement and Development of Basic Slag, formed by the Ministry of Agriculture and Fisheries, the Institute is represented by Dr. A. Cooper, Mr. M. Mannaberg, Mr. G. Hatton, C.B.E., and Mr. B. Talbot; on the Grey and Malleable Iron Research Committee of the Department of Scientific and Industrial Research by Professor T. Turner; on the Technical Committee of Lloyd's Register of Shipping by Lord Invernairn and Mr. W. Simons; and on the Board of Governors of the School of Metalliferous Mining (Cornwall) by Professor H. Louis. Mr. M. Mannaberg is the representative of the Council on the Council of the Institution of Fuel Technology.

Sir Robert Hadfield, Bt., represents the Institute on the British Association Fuel Economy Committee, on the Court of Sheffield University, and on the Home Committee for the University of Hong Kong; while Sir W. Peter Rylands acts similarly on the Court of the University of Liverpool.

Mr. Frank W. Harbord, C.B.E., has been appointed to represent the Institute on the newly formed Mechanical Warfare Board called into being by the Army Council.

CHANGES ON THE COUNCIL.

At the Annual Meeting in May 1927 Mr. Frank W. Harbord, C.B.E., was elected President of the Institute, and Mr. B. Talbot has been nominated by the Council to succeed in the Presidency at this Annual Meeting of 1928.

Mr. E. H. Saniter was elected Vice-President to fill the vacancy caused by Mr. Harbord's accession to the Presidency, and Mr. W. G. Gray has been elected a Member of Council to take the seat vacated by Mr. Saniter.

Lieut.-Col. Maurice L. Bell, Dr. W. H. Hatfield, and Mr. A. O. Peech have been elected Members of Council to fill three seats which became vacant at the end of 1926.

In accordance with Byelaw 10, the names of the following Vice-Presidents and Members of Council were announced at the Autumn Meeting as being due to retire at the Annual Meeting, 1928.

Vice-Presidents—Mr. George Hatton, C.B.E. ; Mr. Alfred Hutchinson ; and Mr. William R. Lysaght, C.B.E.

Members of Council—Mr. E. H. Saniter ; Mr. John Craig, C.B.E. ; The Hon. R. D. Kitson, D.S.O., M.C. ; Mr. Cyril E. Lloyd, M.P. ; and Professor Cecil H. Desch, F.R.S.

Mr. Saniter having since been elected a Vice-President, Mr. W. Simons, being next due to retire, now retires in his place.

No other members having been nominated up to one month previous to the Annual Meeting, the retiring members, in accordance with the announcement made at the Autumn Meeting, but subject to the change specified, are presented for re-election.

THE IRON AND STEEL INSTITUTE.
BALANCE SHEET, DECEMBER 31, 1927.

LIABILITIES.				ASSETS.			
Sundry Creditors :—				Sundry Debtors :—			
Journal Printing	...	...	£2,451 19 1	Subscriptions in arrear, since received	...	...	£155 18 6
Journal Abstracts	...	...	69 14 0	Journal Sales, since received	...	...	131 4 2
Journal Postage	...	...	147 13 6	Interest on Investments, since received	...	...	243 14 0
Library Books and Binding	...	...	8 7 7	Amount due from Carnegie Scholarship Fund...	...	...	132 18 5
Office Rent, &c.,	...	...	272 13 2	Telephone Deposit	...	...	1 0 0
Autumn Meeting	...	...	3 8 3	Miscellaneous	...	...	27 3 5
Stationery, Printing, Postage, &c.,	...	...	93 14 4	Payments in Advance :—	...	...
Amount due to Special Purposes Fund	...	...	1 1 0	Autumn Meeting 1928	...	...	46 3 2
Miscellaneous	...	...	1 2 2	Library books, &c.	...	...	11 7 4
			£3,052 13 1	Investments, at cost, as per Schedule :—	...	...
Subscriptions received in advance	...	...	77 12 9	(General Fund	...	...	...
Journal Sales, Amount received in advance	...	...	40 16 8	(The Market Value of these Securities at 31st December 1927 was £11,749 8s. 3d.)	...	...	15,562 12 5
Iron and Steel Institute Capital Account :—	...	...		Cash at Bank and in Hand :—	...	...
As per last Balance Sheet	...	...	15,683 10 5	General Account	...	...	214 11 2
Deduct Excess of Expenditure over Income for Year to 31st December 1927	...	...	879 4 2	Deposit Account	...	...	1,100 0 0
			14,804 6 3	Secretary's Account	...	...	340 16 4
				Cash at Office	...	...	1 19 10
			£17,975 8 9	Life Compositions Fund :—	...	...	£17,975 8 9
Life Compositions Fund :—	...	...		* Investments, at cost, as per Schedule	...	...	2,990 4 3
As at 1st January 1927	...	...	3,095 4 3	Cash at Bank	...	...	178 10 0
Add Fees received during year	...	...	73 10 0	*(The Market Value of these Securities at 31st December 1927 was £2,258 13s. 11d.)	...	...	3,168 14 3
				Carnegie Scholarship Fund :—	...	...
Carnegie Scholarship Fund :—	...	...		* Investments, at cost, as per Schedule	...	...	24,153 6 10
Sundry Creditors—	...	...		Interest on Investments accrued due at 31st December 1927, since received	...	...	592 3 0
Printing and Posting of Memoirs	...	£461 7 2		Cash at Bank on Deposit Account	...	...	248 16 4
Miscellaneous Printing	...	7 15 7		*(The Market Value of these Securities at 31st December 1927 was £23,562 15s. 0d.)	...	...	24,994 6 2
Grants due 1927	...	300 0 0			...	...
Amount due to Institute's General Fund	...	132 18 5			...	...
	...	902 1 2			...	...
	...	21,241 5 6			...	...
Amount of Fund	...				...	...
Add Accumulated Surplus Income :—	...				...	...
As at 1st January 1927	...	2,877 9 9			...	...
Deduct Excess of Expenditure over Income for Year to 31st December 1927	...	26 10 3			...	...
			2,850 19 6		
Carried forward	...		24,994 0 2		
			£46,138 9 2		£46,138 9 2

STATEMENT OF ACCOUNTS.

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LIABILITIES.		ASSETS.	
Brought forward ...	£46,138 9 2	Brought forward ...	£46,138 9 2
Special Purposes Fund :—		Special Purposes Fund :—	
Capital Account, representing subscriptions received 1919–20, invested <i>per contra</i> ...	£9,451 0 0	Amount due from General Fund ...	£ 1 1 0
Income and Expenditure Account :—		* £12,242 19s. 3d., 4% Funding Stock (1960–90) 9,512 7 5	
Balance at 1st January 1927 ...	£974 2 3	Cash at Bank :—	
Less Excess of Expenditure over Income for Year to 31st December 1927 ...	327 18 1	Current Account ...	£66 11 2
		Deposit Account ...	517 4 7
	646 4 2		583 15 9
Williams Prize Fund :—		* (The Market Value of this Security at 31st December 1927 was £10,773 16s. 2d.)	10,097 4 2
Capital Account, representing the Market Value of £3,000 3½% Conversion Loan at 21st September 1926, when the Fund was inaugurated ...	2,220 0 0	Williams Prize Fund :—	
Income and Expenditure Account :—		Income Tax recoverable, since received ...	21 0 0
Balance at 1st January 1927 ...	37 17 6	* £3,000 3½% Conversion Loan (at cost) ...	2,220 0 0
Add Excess of Income over Expenditure for Year to 31st December 1927 ...	21 0 0	Cash at Bank ...	37 17 6
	58 17 6	* (The Market Value of this Security at 31st December 1927 was £2,302 10s.)	2,278 17 6
	2,278 17 6		
	<u>£58,514 10 10</u>		<u>£58,514 10 10</u>

SPECIAL PURPOSES FUND.

INCOME AND EXPENDITURE ACCOUNT FOR THE YEAR ENDED DECEMBER 31, 1927.

INCOME.		EXPENDITURE.	
To Interest on Funding Stock ...	£391 15 6	By Grants :—	
" Interest on Deposit ...	18 9 2	British Refractories Research Association ...	£25 0 0
		British Engineering Standards Association ...	50 0 0
		University College (Ramsay Memorial Laboratory) ...	52 10 0
		Empire Mining and Metallurgical Congress (Canada) ...	105 0 0
		Expenses of Delegate to Empire Mining and Metallurgical Congress (Canada) ...	135 19 0
" Excess of Expenditure over Income for the Year, carried to Balance Sheet ...	327 18 1	Expenses of Heterogeneity Committee ...	369 13 9
	<u>£738 2 9</u>		<u>£738 2 9</u>

STATEMENT OF ACCOUNTS.

GENERAL FUND.

INCOME AND EXPENDITURE ACCOUNT FOR THE YEAR ENDED DECEMBER 31, 1927.

INCOME.			EXPENDITURE.		
To Entrance Fees	...	...	By Salaries (including Overtime)	...	£3323 16 10
" Annual Subscriptions :—	...	...	" Office Rent, Cleaning, &c...	...	1073 11 9
Members—Home	...	£1074 0 0	" Library Books and Binding	...	146 6 8
Do. Foreign	...	1555 17 9	" Office Furniture	...	6 4 9
Associate	...	29 8 0	" Autumn Meeting	...	290 1 9
" Journal Sales	...	...	" Annual Meeting	...	146 11 7
" Interest on Investments :—	...	...	" Journal Publishing Expenses :—	...	...
General Fund, <i>Less</i> Tax	...	...	Printing, &c.	...	£2488 3 10
Life Compositions Fund, <i>Less</i> Tax	...	...	Abstracts...	...	149 13 3
Bessemer Medal Fund :—	...	...	Translations	...	25 0 0
Interest on Investment, <i>Less</i> Tax	...	12 16 0	Postages	...	147 13 6
Income Tax recovered	...	3 4 0	" Stationery and Printing (including copies of Papers)...	...	2810 10 7
" Interest on Deposit	...	...	" Postage and Receipt Stamps	...	557 2 3
" Sale of Waste Paper	...	...	" Travelling Expenses	...	121 16 11
" Sundry Receipts	...	...	" Insurance	...	16 19 5
	...	...	" Telephone Rental and Calls	...	22 9 6
	...	...	" Auditor's Fees	...	16 13 6
	...	...	" Bessemer Medals	...	31 10 0
	...	...	" Compassionate Allowance	...	28 15 0
	...	...	" Office Disbursements and Sundry Payments	...	50 0 0
" Excess of Expenditure over Income for the Year, carried to	67 15 1
Balance Sheet	...	879 4 2	
	£8710 5 7
	...	£8710 5 7	

STATEMENT OF ACCOUNTS.

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ANDREW CARNEGIE RESEARCH SCHOLARSHIP FUND.

INCOME AND EXPENDITURE ACCOUNT FOR THE YEAR ENDED DECEMBER 31, 1927.

INCOME.		EXPENDITURE.	
To Interest on Investments:—		By Scholarship Grants	£625 0 0
£2250 Newcastle-upon-Tyne Electric Supply		Printing Memoirs	422 16 2
4½ per cent. Consolidated First Mortgage		Postage of Memoirs	60 0 0
Debenture Stock	£81 0 0	Salaries	52 0 0
£7925 London & North Eastern Railway	253 12 0	Cost of Medals	43 2 6
4 per cent. Debenture Stock	42 0 0	Miscellaneous Printing and Stationery	8 10 4
£1312 London & North Eastern Railway	210 0 0		
4 per cent. 1st Guaranteed Stock	64 0 0		
£8750 London & North Eastern Railway	48 0 0		
3 per cent. Debenture Stock	76 16 0		
£2000 London Midland & Scottish Railway	80 10 0		
4 per cent. Debenture Stock	39 16 0		
£1500 Great Western Railway 4 per cent.	75 8 4		
Debenture Stock	£971 2 4		
£2580 4s. India 3 per cent. Stock	10 5 11		
£2300 India 3½ per cent. Stock	203 10 6		
£1000 5 per cent. War Stock, 1929-47	£1184 18 9		
£2693 12s. 3¼ per cent. Conversion Loan	26 10 3		
Interest on Deposit	£1211 9 0		
" Income Tax recovered to 5th April 1927			
" Excess of Expenditure over Income for the Year, carried to Balance Sheet			

"WILLIAMS PRIZE" FUND.

INCOME AND EXPENDITURE ACCOUNT FOR THE YEAR ENDED DECEMBER 31, 1927.

INCOME.		EXPENDITURE.	
To Interest on 3½ per cent. Conversion Stock	£84 0 0	By Prizes awarded during year	£84 0 0
" Income Tax recovered to 5th April 1927	21 0 0	" Excess of Income over Expenditure carried to Balance Sheet	21 0 0
	£105 0 0		£105 0 0

INVESTMENTS ON ACCOUNT OF GENERAL FUND OF THE INSTITUTE.

£1000 5 per cent. War Stock, 1929-47	£945 16 4
£549 19s. 2d. 3½ per cent. Conversion Stock...	409 11 0
£147 Southern Railway 4 per cent. Debenture Stock	449 2 4
£1872 London & North Eastern Railway 4 per cent. Second Guaranteed Stock	2,148 13 3
£2241 London & North Eastern Railway 4 per cent. First Preference Stock	2,148 13 4
£437 London & North Eastern Railway 3 per cent. First Guaranteed Stock	2,431 14 5
£1500 Buenos Ayres Great Southern Railway 4 per cent. Debenture Stock	376 12 5
£1000 Calcutta 4 per cent. Bonds, 1939	1,594 12 9
£800 Bombay 4 per cent. Bonds, 1939	982 10 0
£79 4s. 5d. "B" Annuity, Scinde, Punjab, and Delhi Railway	809 0 0
£50 1s. 8d. "B" Annuity, Great Indian Peninsula Railway	1,999 0 7
	1,267 6 0
	<u>£15,562 12 5</u>

INVESTMENTS ON ACCOUNT OF LIFE COMPOSITIONS FUND.

£1330 London & North Eastern Railway 3 per cent. Debenture Stock	£1,254 17 6
£335 London Electric Railway 4 per cent. Perpetual Stock	304 14 11
£335 Metropolitan District Railway 4 per cent. Prior Lien Debenture Stock	333 11 2
£376 London & North Eastern Railway 4 per cent. Second Preference Stock	371 0 8
£681 13s. 4 per cent. Funding Loan, 1960-1990	600 0 0
£160 14s. 2d. 3½ per cent. Conversion Loan	126 0 0
	<u>£2,390 4 3</u>

INVESTMENT ON ACCOUNT OF SPECIAL PURPOSES FUND.

£12,242 19s. 3d. 4 per cent. Funding Loan, 1960-1990	£9,512 7 5
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INVESTMENT ON ACCOUNT OF WILLIAMS PRIZE FUND.

£3000 3½ per cent. Conversion Loan	£2,220 0 0
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INVESTMENTS ON ACCOUNT OF ANDREW CARNEGIE RESEARCH SCHOLARSHIP FUND.

£2250 Newcastle-upon-Tyne Electric Supply 4½ per cent. Consolidated First Mortgage Debenture Stock	£2,261 10 0
£7925 London & North Eastern Railway 4 per cent. Debenture Stock	6,466 1 0
£1313 London & North Eastern Railway 4 per cent. First Guaranteed Stock	880 11 11
£3750 London & North Eastern Railway 3 per cent. Debenture Stock	5,611 2 8
£2000 London Midland & Scottish Railway 4 per cent. Debenture Stock	1,693 0 6
£1500 Great Western Railway 4 per cent. Debenture Stock	1,204 5 3
£2560 4s. India 3 per cent. Stock	1,525 3 3
£2300 India 3½ per cent. Stock	1,600 2 9
£1000 5 per cent. War Stock, 1929-1947	905 10 6
£2693 12s. 3½ per cent. Conversion Loan	2,006 19 0
	<u>£24,153 6 10</u>

(Signed) H. C. H. CARPENTER, *Hon. Treasurer*. G. C. LLOYD, *Secretary*.

I have examined the foregoing Balance Sheet and Income and Expenditure Accounts with the Books and Vouchers of the Institute, and certify them to be correct. I have also verified the Balances at the Bankers and the Securities for the Invested Funds shown above.

(Signed) W. B. KEEN, *Chartered Accountant*.

BESEMER MEDAL FUND—(Trustees: Sir Hugh Bell, Bart., Lord Airedale, and Francis Samuelson, Esq.)
 £400 London Midland and Scottish Railway 4 per cent. Debenture Stock.

INDUCTION OF THE NEW PRESIDENT.

The PRESIDENT said the very pleasing duty now devolved upon him of inducting the new President into the Chair. The members knew Mr. Benjamin Talbot so well that really no introduction was needed, and all it was necessary to do was to ask Mr. Talbot to accept the high office to which the members had elected him. The members knew that Mr. Talbot would devote his great abilities to furthering in every way the interests of the Institute. His long and wide experience, both on the technical and business side of the Institute, would enable him to render services which other men might not have been able to perform to the same degree. In handing over the office to Mr. Talbot he knew perfectly well that the new President would have the real interest of the Institute at heart, and that the members could rely upon him to maintain in every way the dignity and prestige of the Institute. He now had much pleasure in asking Mr. Talbot to take the Chair as President of the Institute.

[The Chair was then vacated by Mr. Harbord, and taken, amid very hearty applause, by Mr. Benjamin Talbot.]

The PRESIDENT (Mr. Benjamin Talbot) said he considered that by his election to the high office of President the greatest honour but one which he had ever received had been conferred upon him, as he ranked the receipt of the Bessemer Medal in front even of the Presidency of the Institute. When he joined the Institute he never expected that one day the members would think him sufficiently important to occupy the Presidential Chair. If he received the help of the members he was sure he would be able to keep the flag flying, but it must be realised that he would have to depend upon the help of all the individual members to keep the Institute going. He again thanked the members for the great honour which they had done him.

Sir ROBERT HADFIELD, Bt. (Past-President), said it was his very pleasing duty to propose that a hearty vote of thanks be accorded to the retiring President, Mr. Harbord, who had given unlimited time and very able help in the conduct of the affairs of

the Institute. He had done everything he possibly could to maintain the reputation of the Institute in the very important visits which had been paid to Sweden and to Glasgow; and, although Mr. Harbord had now vacated the Chair, he was quite sure the Institute could rely in the future on receiving the aid of his very valuable services in its interests.

The resolution of thanks was carried by acclamation.

Mr. F. W. HARBORD, C.B.E. (Past-President), thanked Sir Robert Hadfield for the very kind words he had used in proposing the resolution, and the members for the very hearty manner in which they had accepted them. He could only say he had done his best as far as he could to forward the interests of the Institute. He had taken a great delight in the work and had thoroughly enjoyed it, and he could only hope that he had fulfilled his duties to the satisfaction of the members.

PRESENTATION OF THE BESSEMER GOLD MEDAL TO
MR. CHARLES M. SCHWAB.

The PRESIDENT: My first duty is a very pleasant one, and that is to present the Bessemer Gold Medal to Mr. Charles M. Schwab, President of the American Iron and Steel Institute, and the President of the Bethlehem Steel Corporation.

The Council of the Iron and Steel Institute, in considering the award of the Bessemer Medal, must be influenced by distinguished contributions to the progress of the industry, whether by research, the application of scientific principles, or operative ability. It is perhaps unusual, and it is indeed one of the rare combinations for which the industry is invariably seeking, to find in one personality the three qualities of scientific knowledge, technical ability, and administrative capacity, but in Mr. Schwab we have an outstanding example of such a combination linked with force of character, as the result of which he has, by his own ability and energy, forged his way to the leading position in the great iron and steel industry of the United States of America.

Mr. Schwab was born in Williamsburg, Blair County, Pa., on February 18, 1862, and started his distinguished career in the

Edgar Thomson Steelworks of the Carnegie Company in the somewhat subordinate capacity of driving stakes at a dollar a day. By his own energy and ability he rose in a period of seven years to the position of chief of the Engineering Department of the Carnegie Company.

The great Homestead Steelworks plant, designed by him, and erected under his supervision, was arranged to be a practically continuous mill, so that the raw materials went in at one end and the finished products came out at the other. In 1892 Mr. Schwab was appointed Superintendent of the Edgar Thomson Steelworks, and, after a very difficult period in the history of labour in the American steel industry, was also appointed Superintendent of the Homestead plant.

In the year 1896 he was made a member of the Board of Managers of the Carnegie Company, and in the following year, at the age of 35, was elected as its President.

The problem in the United States at that time was the manufacture of more steel, better steel, and more rapid production. In this Mr. Schwab achieved the best practical results, and the Presidency of the Carnegie Company was the reward he gained in that competition. As President he made the position of this company stronger and stronger. Smaller concerns were combined until the company attained an impregnable position in relation to raw materials, to modern equipment, and to skilful management, with Mr. Schwab, foremost amongst the world's practical steel-makers, at the head of the company.

Whilst the technical side of the business was progressing in a manner unprecedented in the history of the world, the commercial results obtained at that time were unsatisfactory owing to the competition between rival firms, and it was realised that, if further commercial development on economic lines was to be made possible, a fusion of interests between the larger companies was necessary. It was chiefly due to the ability of Mr. Schwab, who was the intermediary between Mr. Carnegie and the other parties to the bargain, that a consolidation was effected, and the United States Steel Corporation came into being with Mr. Schwab as President. Thus at the age of 39 he became President of the world's greatest corporation, and his organising genius was responsible for the most gigantic working force and the most

complete industrial system ever put together in the service of a private corporation.

Mr. Schwab resigned his Presidency of the United States Steel Corporation after three years and obtained a controlling interest in the Bethlehem Steel Corporation, of which he is now Chairman of the Board of Directors. The Bethlehem plant at that time was largely engaged in the manufacture of munitions. Under the control of Mr. Schwab it has become one of the most magnificent steelworks in the world, and at the present time the manufacture of munitions takes up less than 5 per cent. of the productive capacity of the plant. It is conducted on entirely independent lines, and is second only to the United States Steel Corporation.

Apart from his contributions to the advancement of the manufacture of iron and steel, this country is under a great debt of gratitude to Mr. Schwab for the very eminent services he rendered to the cause of the Allies in the Great War in the production of munitions, and later, when our mercantile marine was being weakened by the activity of enemy submarines, by the tremendous efforts he made as Director-General of the Emergency Fleet Corporation to provide ships for the conveyance of the American armies, stores, and equipment to France at the most critical period in the war.

Mr. Schwab, may I express to you, on behalf of the Members of the Iron and Steel Institute, our very great pleasure in seeing you here to-day? We are sensible of the honour you do to the Institute by accepting the Bessemer Medal, which is the highest honour we have to bestow, and which we consider to be the hall-mark of outstanding technical ability and efficiency so far as the iron and steel industry is concerned.

[The President then presented the Medal to Mr. Schwab.]

Mr. CHARLES M. SCHWAB, in acknowledging the presentation of the Medal, said: Mr. President, Members of Council and my friends, Members of the Iron and Steel Institute, when Mr. Talbot speaks of the days gone by it seems almost impossible for me to realise that I am to-day practically the dean of the steel industry of America. I am rounding out my fiftieth year

of service this year in the manufacture of iron and steel. I have received a good many honours in life in different directions, but they all pale into insignificance in my own estimation and opinion compared with the receipt of the Bessemer Medal, which has always stood as the hall-mark of what has been greatest in our business. There is no American that bears a warmer love or feeling for his British brethren than does your humble servant. I am one of the men in America that openly believe and state that, while we were not able to contribute in man-power to the Great War, it was our duty, rich as we are, to contribute in money; and I am not in sympathy with the people who are endeavouring to extract dollars or pounds from the men who stood together in that great struggle.

Mr. President, how well I remember you in 1892 and subsequent years! How little I then dreamed that you would occupy the honoured office you now hold; and although I dreamed of the Bessemer Medal, how little I dreamed that at this late date in life the honour would come to me, and how happy I am that it has come to me through the hands of you, Mr. President, one of my oldest friends! Gentlemen, I have grown rich and wealthy in manufacturing and all that sort of thing in these years, but it does not count anything to me. At this time of life the one thing that does mean much to me is the approval of those with whom I have been for so many years associated, and to have this token of approval from you means more than anything that I can possibly find words to express. I was in Europe two months ago, when I was notified by Mr. Harbord, your then President, and by your Secretary, Mr. Lloyd, that this medal was to be conferred upon me. I have just been home for two weeks, and although duties are pressing and I am not young, and although I have crossed the Atlantic 80 times in 43 years, nothing could stand in the way of my making a trip across the Atlantic again for the sole purpose of personally expressing to you, Mr. President my friend, and you, gentlemen, my appreciation of the great honour which you have done me. I am going back the day after to-morrow to America, but I take with me a happy heart—a heart overflowing with appreciation for your kindly remembrance of the old American steel-master. The last time I attended one of your meetings was 43 years ago, and

I came here with the great American steel-master, Captain Bill Jones, the inventor of the mixer and other things used in every steelworks of the world to-day.

This medal will go amongst my valued possessions as the most valued of all my possessions. I have no son to leave it to and no family coming after me, but it shall retain a place in the archives of the American iron and steel industry, and it will do me more honour and give me more pride and a greater sense of satisfaction than anything that has ever come to me in my long and busy life. Thank you, Mr. President; thank you, Members of the Council; thank you, my personal friends of whom I have many here; thank you, gentlemen of the British Iron and Steel Institute, members of this great and glorious Empire of yours, for your acknowledgment of an American industrial citizen, whose heart is with you, and who believes that in the bosom of our family here civilisation and the advancement of the world depend on a close alliance and understanding of our two great English-speaking nations.

The PRESIDENT said he was sure Mr. Schwab would be pleased to know that Mr. Farrell, the President of the United States Steel Corporation, had sent him the following cable :

“Accept the gratitude of our industry in the United States for the high honour conferred upon my colleague, Charles M. Schwab.”

The Presidential Address was then delivered (see p. 33), and the following papers were read and discussed :

E. C. EVANS and F. J. BAILEY : “Blast-Furnace Data and their Correlation.”

J. H. JONES, J. G. KING, and F. S. SINNATT : “Reactivity of Coke.”

A. CROOKE and T. THOMSON : “The New Plant of the Appleby Iron Co., Ltd.”

H. J. TAPSELL : “The Fatigue-Resisting Properties of 0·17 per cent. Carbon Steel at Different Temperatures and at Different Mean Tensile Stresses.”

J. A. JONES : “The Properties of Nickel Steels, with Special Reference to the Influence of Manganese.”

A. B. EVEREST and D. HANSON : "The Influence of Nickel in Iron-Carbon-Silicon Alloys containing Phosphorus."

J. SWAN : "The Effect of Silicon on Tungsten Magnet Steel."

SECOND REPORT OF THE COMMITTEE ON THE HETEROGENEITY OF STEEL INGOTS.

V. HARBORD : "A Comparison of the Most Important Methods Employed in the Cleaning of Blast-Furnace Gas."

W. H. HATFIELD : "Heat-Resisting Steels. Part II.—Mechanical Properties."

T. SWINDEN and P. H. JOHNSON : "Chromium Steel Rails."

J. NEWTON FRIEND : "A Study of the Resistance of Over-Stressed Wrought Irons and Carbon Steels to Salt-Water Corrosion."

W. E. WOODWARD : "The Rapid Normalising of Overstrained Steel."

The following papers were taken as read :

J. E. HOLGATE and R. R. F. WALTON : "Blast-Furnace Practice in Natal."

A. WESTGREN, G. PHRAGMÉN, and TR. NEGRESKO : "On the Structure of the Iron-Chromium-Carbon System."

A. L. NORBURY and T. SAMUEL : "The Recovery and Sinking-In or Piling-Up of the Material in the Brinell Test and the Effects of these Factors on the Correlation of the Brinell with Certain Other Hardness Tests."

H. O'NEILL : "Twin-Like Crystals in Annealed α -Iron."

CARNEGIE RESEARCH GRANTS.

The SECRETARY announced that applications for grants were received from six candidates and, after careful investigation of all the applications, the Council had decided that grants of the amounts shown below be awarded to the following applicants :

DAVID BINNIE (Glasgow), £100, to continue a research under the direction of Professor Andrew on behalf of the Committee on Heterogeneity of Steel Ingots. The investigation aims at determining the liquidus and solidus of carbon and alloy steels and studying the reactions of sulphides in liquid and solid steels.

B. S. SMITH (Sheffield), £100, to assist in continuing an investigation under the direction of Professor Desch on the viscosity and

density of molten steel, which is being carried out at Sheffield University on behalf of the Committee on Heterogeneity of Steel Ingots.

HENRY TEMEL (Kladno, Czecho-Slovakia), £50, to assist him in carrying out a research on the determination of the sulphur contents of slag of the open-hearth process.

JOSEPH VIETORISZ (Budapest), £50, to assist him in carrying out a research on the malleability of rolled or forged iron and steel.

INVITATION TO MEET IN THE UNITED STATES IN 1932.

At the Council Meeting, held on the morning of May 3, 1928, Mr. Charles M. Schwab, President of the American Iron and Steel Institute, presented two sealed letters, from the American Institute of Mining and Metallurgical Engineers and the American Iron and Steel Institute respectively, conveying an invitation to the Iron and Steel Institute to meet in the United States in 1932.

The letter from the American Institute of Mining and Metallurgical Engineers recalled the visits paid by the British Iron and Steel Institute to the States in 1890 and 1904, and also the visit of the American Institute to Great Britain in 1906, and, in extending a cordial invitation to revisit the States in 1932, assured the Iron and Steel Institute of a sincere welcome. It expressed the conviction that the exchange of such visits would contribute in an important degree to the mutual understanding which was so essential for the sane solution of all international economic problems, and that the common pool of knowledge and experience resulting from such periodical opportunities for personal and friendly contact could not fail to multiply the effectiveness and enhance the usefulness of the profession of metallurgy.

The Directors of the American Iron and Steel Institute, in extending an equally gracious invitation, also referred to previous visits of the British Iron and Steel Institute to America, and of the American Institute to London. They felt that the best interests of both the British and American iron and steel industries would be served by such a visit, and assured the British Institute of a most cordial welcome.

The President, Council, and members expressed their grateful acknowledgments, and cordially accepted the joint invitation of the two American Institutes to meet in the United States in 1932.

PRESIDENTIAL ADDRESS.

By B. TALBOT.

If the addresses of Past-Presidents, many of them scientific and technical men eminent in their day, were put together they would form very interesting reading, as they record the advances of the iron and steel industries during the past years very clearly and they cover the ground thoroughly. I have found it somewhat difficult to select a subject for my address, but finally came to the conclusion that possibly an account of my forty years' personal experience in the development of the basic open-hearth process might be of general interest.

Just before the advent of the basic process, or a little over 50 years ago, A. L. Holley, the most noted American metallurgist and steelworks engineer of his day, wrote in one of his reports in summing up his conclusions about the open-hearth process as follows :

“ While the Bessemer process has reached a high degree of perfection, so high, indeed, that the directions of great improvement are not obvious, the open-hearth is availing itself of new accessories in every direction. The Bessemer looks back to a splendid development. The open-hearth looks forward to a splendid development.

“ In this country [U.S.A.] to-day, the Bessemer is by far the cheaper method of producing the ordinary and some of the finer grades of structural steel. The product is not only cheap, but when made of the best materials, and with the skill and care that many of our experts can bestow, it is trustworthy and excellent.

“ The open-hearth process, on the contrary, is performed mostly in small furnaces and in works too limited to fully economise labour and maintenance. It receives no aid from any preliminary preparing or refining operation. Excepting in a few details, and in the arrangement of a few works, the plant is little better than it was five or six years ago. The practice, however, in most of our works is excellent, and the product of some of them is not

exceeded in quality anywhere in the world. For very soft, very hard, and very pure products, and for steel castings, the present open-hearth has great advantages over the Bessemer. The materials, however, are of the most expensive character.

"But what are the indications of the future? The Bessemer must be chiefly confined to irons very regular in silicon, and hence the most costly to make—to irons pretty low in phosphorus and so requiring ores that average the dearest—to crude irons that are not purified from phosphorus, because they would then also be purified from silicon, and would not be hot enough to blow. If remelting the pig is saved by working directly from the blast-furnace, then the ores and the blast-furnace practice must still be more regular and costly.

"The open-hearth has these advantages, some of them secured and some within reach :

"1. It is not dependent for temperature on the ingredients of the materials, hence as far as heat is concerned it can digest anything that bears the name of iron.

"2. It can, as well as the Bessemer, take its material direct from the blast-furnace or from the cupola.

"3. The greater part or the whole of its materials can be purified by a preliminary process, and hence the cheapest ores can be used whatever their quality. This can be done in whichever of three ways is best suited to the particular case :

"(a) The direct process, as by the Siemens rotator.

"(b) Fluid refining, as by Bell's and Krupp's methods.

"(c) Mechanical puddling.

"4. Very impure scrap, such as old iron rails, may be purified, in connection with pig, by fluid refining.

"The conclusion is inevitable that the open-hearth process is about entering upon a development which will largely increase the use of steel, not only as a substitute for wrought iron and cast iron, but with new adaptations and in new directions."

The late S. T. Wellman once recalled a prophecy by Holley that the open-hearth process would some day go to the funeral of the Bessemer, and, judging from the foregoing quotation from Holley's report in 1877, he certainly anticipated a much greater future development in the open-hearth than in the Bessemer.

The world's output of steel in 1878 was some 2,780,000 tons, which was divided amongst the various steel-producing countries as follows :

	Tons.
Great Britain . . .	980,000
United States . . .	730,000
Germany . . .	460,000
France . . .	280,000
Belgium . . .	120,000
Russia . . .	100,000
Austria . . .	90,000
Sweden . . .	2,000
Total . . .	2,762,000

The British output for the year 1878 was made up as follows :

	Tons.
Acid Bessemer . . .	806,208
Acid open-hearth . . .	175,438
Total . . .	981,646

Mr. Edward Williams stated in his Presidential Address in 1879 that the world's production of open-hearth steel in 1878 was 350,000 tons, which was all acid.

According to information kindly supplied by Mr. M. S. Birkett, of the National Federation of Iron and Steel Manufacturers, the total world production of steel ingots and castings in 1927 is estimated at 99,090,000 tons, of which 12,100,000 tons were acid, and 83,880,000 tons were basic, the remainder being steel made in the electric furnace or in small converters. Of the 83,880,000 tons of basic steel, 64,180,000 tons were made in the basic open-hearth.

When we see the enormous increase in consumption of steel in 50 years, and especially how the output of the open-hearth process has grown in this period, it shows that Holley was correct in his forecast of the increase in the uses of open-hearth steel. As to the statement credited to him by S. T. Wellman that the open-hearth steel process would attend the funeral of the Bessemer, the time has not yet arrived to make even tentative arrangements for its obsequies. In fact, it looks as if both processes will work together for an indefinite period, as there is room for both so long as the cost of producing basic Bessemer steel is less than that of basic open-hearth, and there may be some purposes for which Bessemer steel is preferred.

Holley's report was written before S. G. Thomas announced to the world his epoch-making invention, in his paper read in the spring of 1879, in which he proved that he had successfully dephosphorised pig iron in a basic-lined converter, and had produced a satisfactory quality of steel. This great invention stopped all further development of mechanical puddling, as well as the work on preliminary dephosphorising, which had been solved by Sir Lowthian Bell in this country and by Krupp in Germany in their washing processes. If the basic process had not been invented at that time, no doubt there would have been interesting developments in these preliminary slag-washing refining processes, as it had been discovered that it was possible to dephosphorise at a comparatively low temperature and yet retain carbon in the liquid bath.

It was fortunate that Bessemer was an exceptionally able mechanical engineer as well as a great inventor, as his process was so revolutionary. There has been very little fundamental change in the design of the tilting converter since he finished with it, except in regard to size, although A. L. Holley made certain improvements of detail in the converter, such as the movable bottom, which enabled the tuyeres to be changed more rapidly, and also in the general layout of the converting department.

When S. G. Thomas invented the basic process he had the benefit of the engineering experience and skill of Bessemer, Holley, and others. His task was to perfect his basic lining, make it more durable, and find out the exact composition of the liquid metal which gave best results in the converter, just as Bessemer had to do in his early experiments.

As soon as it was seen that the basic process was a success in the converter, it was taken up by those who were interested in the Siemens open-hearth process, and here again a furnace was at hand ready to be adapted. While Siemens had conceived and worked out successfully the beautiful principle of regeneration in his furnace, and while Bessemer was developing his process, comparatively little improvement in design of the open-hearth had been made since the first furnace was built.

The Siemens furnace in use at that time, as designed for the acid process, gave sufficiently good results, but it was soon found that with a basic hearth it was very expensive to maintain and

repair. The design of this first type of furnace is shown in Fig. 1, the hearth being supported more or less by the regenerators, as they were exactly underneath. The gas and air ports and uptakes were too near together, and air spaces for cooling were inadequate. No doubt if the Siemens patents were investigated we should find more satisfactory designs, but at that time the limited amount of available capital made it extremely difficult to experiment with larger furnaces of different designs. The pioneers of the basic

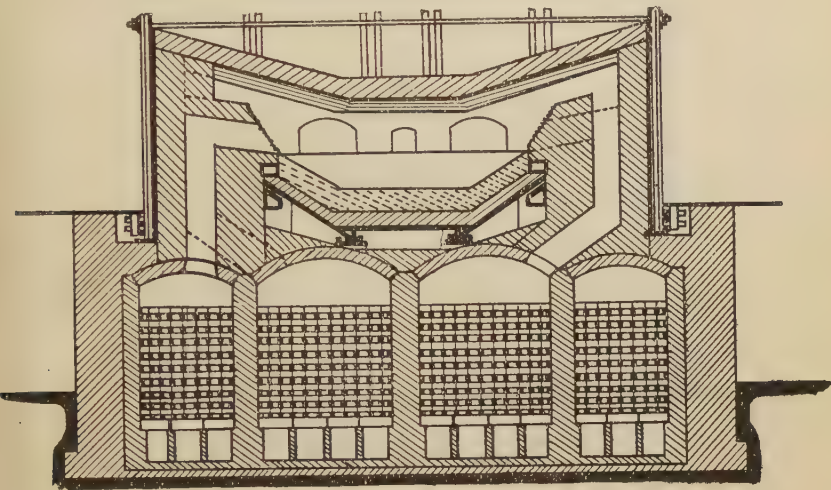


FIG. 1.—Siemens Open-Hearth Furnace.

open-hearth process, however, soon found the old design unsatisfactory in practice, and modified forms of furnaces were introduced.

In 1884 we find in the *Journal of the Iron and Steel Institute* a paper by Mr. Dick on the Batho furnace, the design of which was the result of the joint effort of Messrs. Wailes, Hackney, Riley, and Dick (see Fig. 2). Here we see a practical change in design from the original Siemens. It contained good and bad points. The good points were in the removal of the regenerators to the end, and in the independent support of the hearth on columns or piers, so that free access was possible underneath the hearth. The bad points were the circular hearth, movable roof, and air ports through the roof at right angles to the gas port. In addition to

improving the design of the furnace, the question of suitable pig iron was involved. Some of the pioneers made their work more expensive and difficult by using Staffordshire cinder pig, which was the cheapest iron then produced, but very unsuitable for the purpose on account of the great variation in the percentage of silicon and sulphur, and the exceedingly high phosphorus. This was mainly the reason why such small outputs were obtained, and why the working campaign of a furnace was so short, while the repairs were excessive, owing to the necessity of keeping heats in

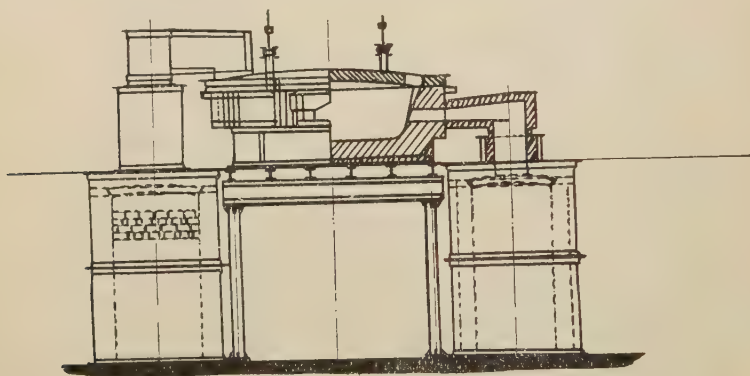


FIG. 2.—1880. 6-ton Basic Furnace. Batho Furnace,
Circular Bath.

the furnace for long periods in order to obtain steel sufficiently low in phosphorus and sulphur. Although Thomas and Gilchrist had previously mentioned in their paper that the basic process should work in the open-hearth, the first published account of the basic open-hearth process that I have come across is contained in Mr. Gillott's paper, read in 1883-84 before the Institution of Civil Engineers, describing the working of a small 2- to 3-ton furnace at the Farnley Ironworks in 1882. Here they used a reasonable mixture of phosphoric pig iron and scrap, and claimed to have obtained satisfactory results.

In Staffordshire, about 1884, Mr. Wailes began to produce basic open-hearth steel at the Patent Shaft Works, but he used a most impure pig iron, which made the operation difficult and expensive. Lincolnshire pig iron at that time, although more

expensive than cinder pig iron, would have yielded more economical results.

Mr. J. H. Darby about that time erected basic open-hearth furnaces at Brymbo, and having blast-furnaces under his control was able to make a basic pig iron low in silicon and sulphur suitable for the process, and credit is due to him for some of the most important pioneer work done. His method for making high-carbon steel by the addition of solid carbon was a most important step in the development of basic open-hearth practice, and it is now in use in almost every basic open-hearth plant which produces rail and medium carbon steels.

Mr. Harbord, our retiring President, read, in 1886, his valuable paper on the basic open-hearth process, which came at the right time, as it lucidly explained the theory and practice of the process, although it will be noticed here that the pig iron used would to-day be considered very unsuitable.

I became interested in the process and commenced work with it in 1887. At the outset I found that Staffordshire common cinder pig was a very difficult metal to employ, as hours were taken to bring the phosphorus and sulphur down to satisfactory limits. To overcome this I used two furnaces, the first to melt the pig iron, desiliconise, and remove some of the phosphorus; the second to finish off the heat. The furnaces were small, being of only 2 to 3 tons capacity, and the following gives the history of a typical heat:

From 2 to 3 tons of cinder pig were charged with oxide and lime and melted in the first furnace, the analysis of the iron being as follows:

	C. %	Si. %	P. %	S. %	Mn. %
As charged cold into first furnace	3.0	1.46	3.96	0.24	1.40
As poured into second furnace .	2.00	Trace	2.60	0.09	0.15
Steel as tapped	0.09	Trace	0.07	0.054	0.46

The steel was tapped two hours after pouring the refined metal into the second furnace. By working in this way it was found that heats were made in less time, the heavy expenditure on repairs was greatly reduced, and the steel produced was of better quality.

Fig. 3 shows a furnace of unusual design for which I was responsible. It was erected and used at the Round Oak Works, Staffordshire, in 1889. The regenerators were put overhead,

since on the only site available there was no room for them anywhere else. This furnace was of 5 to 6 tons capacity, and worked very satisfactorily, making 14 to 15 heats per week. The percentage of pig iron in the charge was less than that usually used at the time, being about 50 per cent., and this caused quicker working. Both the gas-producer and air supplying this furnace were under fan pressure. I have never heard of another being built like it, and no one would put regenerators on the top of

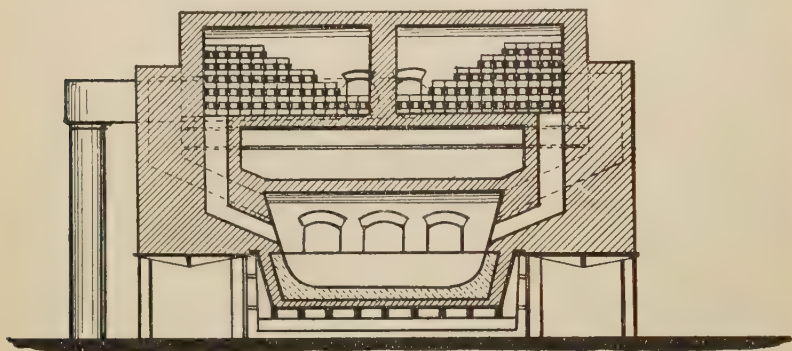


FIG. 3.—1889. 6-ton Basic Furnace with Regenerators superimposed. Round Oak.

a small furnace if it were possible to put them underneath or at the ends.

Good work was being done in one or two other works in England where the basic open-hearth process had been introduced. About 1889-90 Mr. Mannaberg started the process on a considerable scale at the new steelworks put down by the Frodingham Iron Company and erected under his supervision. The pig iron made from Lincolnshire ores was very suitable for the process, and steel of excellent quality was produced, which did much to convince engineers that basic open-hearth steel was a reliable and satisfactory material for general engineering purposes. These works were the first in England to erect a tilting furnace to operate the continuous process.

In 1890 I went to America to introduce the manufacture of basic open-hearth steel in the Southern States. In going through various works there I found a great development in open-hearth

basic practice going on. The Homestead works were putting in a large installation for those days.

In the development of the acid open-hearth in the United States it was fortunate that they had a man of such ability and practical experience as the late S. T. Wellman as a pioneer. What Holley had been to the acid Bessemer, Wellman was to the open-hearth. In 1887 he built at the Otis Steelworks, Cleveland, Ohio, the furnace shown in Fig. 4. In this he departed from the

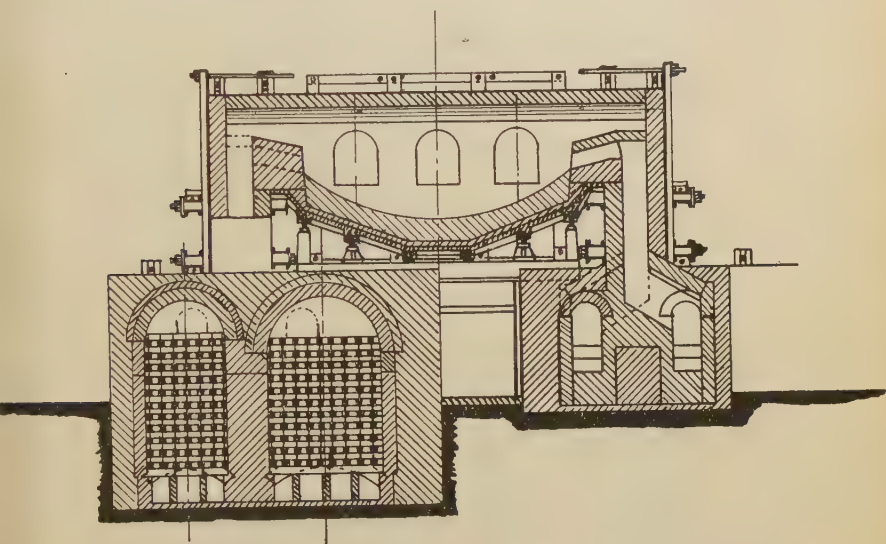


FIG. 4.—1887. 15-ton Acid Furnace with Slag Pockets. (Wellman.)

Siemens design then in use, and in my opinion made a great advance by arranging cinder chambers under the uptakes of the ports, and by moving the regenerators forward, so that the slag could not drop amongst, and rapidly clog up, the spaces between the checker bricks, and also by carrying the weight of the furnace body on girders supported on brick columns independently of the regenerator arches. Shortly afterwards basic open-hearth furnaces were built in the United States on these lines. In fact, one may say that this furnace became a new standard design, and very little alteration was made in the design of fixed basic open-hearth furnaces from about 1895 until comparatively recently, except in

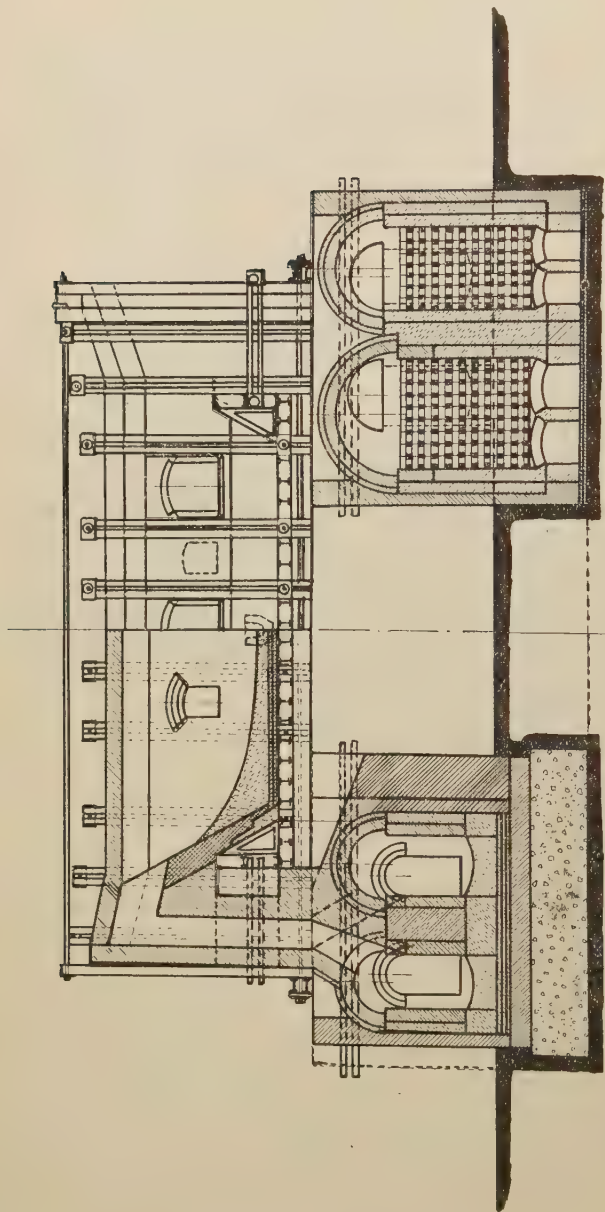


FIG. 5.—1894. 30-ton Basic Furnace. Pencoyd. (Fixed.)

the arrangement of the ports, and, of course, in size, with the necessary increase in strength.

Fig. 5 shows the 30-ton furnace built at Pencoyd, Pa., in 1894. It will be seen that this is very similar to the one designed by Wellman in 1887, and, apart from the port arrangements, there is no great difference between it and the present-day type of furnace, except as regards larger capacity, with more water-cooling, and that waste-heat boilers are now frequently installed. The only alterations are in detail, this furnace being built for basic steel, while Wellman's 1887 furnace was for acid steel; the air-cooling arrangements in the block were also made more effective. It will be noticed that the block has a cooling chamber beneath it, which is provided with apertures passing between the gas and air uptakes to allow air to circulate through. This furnace made 15 to 16 heats per week.

While these basic open-hearth furnaces were being introduced S. T. Wellman brought out a further great improvement, namely, the charging machine, perhaps his greatest invention. This machine made it possible for furnaces of much larger capacity to be easily and rapidly charged, and did away with a large amount of manual labour. It was also a great boon to the furnacemen during the high temperature of the summer months. At that time the small electric motor was coming into use at steelworks for all secondary power, superseding small steam engines and hydraulic power. In fact, those who witnessed these changes in the decade of 1890-1900 would say that the electric drive for charging machines, overhead cranes, roller tables, machines, and tools in steelworks was largely responsible for increasing output and decreasing costs.

H. H. Campbell was the first to use tilting open-hearth furnaces, having put them into operation at Steelton, Pa., in 1889. These furnaces tilted centrally, but as the block was fixed a space had to be left open between the tilting and fixed portions (see Fig. 6). It was in 1895 that S. T. Wellman built his rolling furnace for the Illinois Company, Chicago, and this furnace is shown in Fig. 7 (Plate I.).

In my experiments in 1891-92 on desiliconising the siliceous pig iron in Alabama in fixed furnaces, I had become interested in the tilting furnace, and I had recommended the introduction of

a large basic-lined tilting furnace to run continuously for the purpose of desiliconising the siliceous blast-furnace metal by

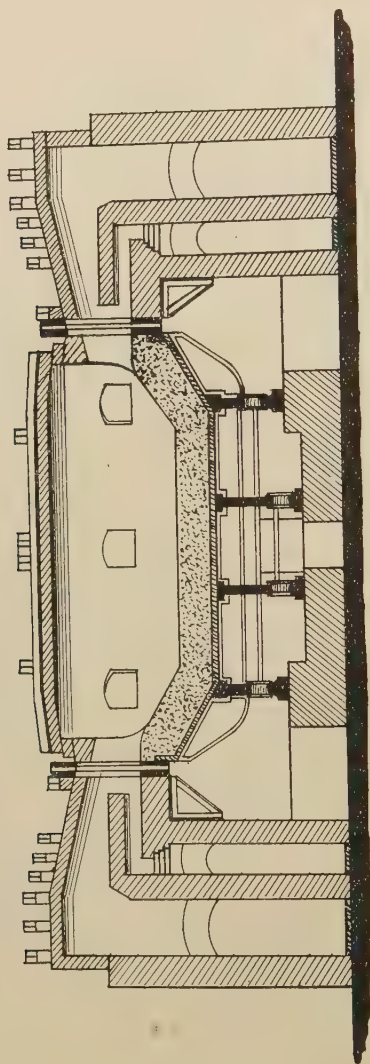


FIG. 6.—1889. Campbell Tilting Furnace.

means of a basic slag instead of using an acid Bessemer converter for the purpose.

When I decided to build a tilting furnace for the continuous

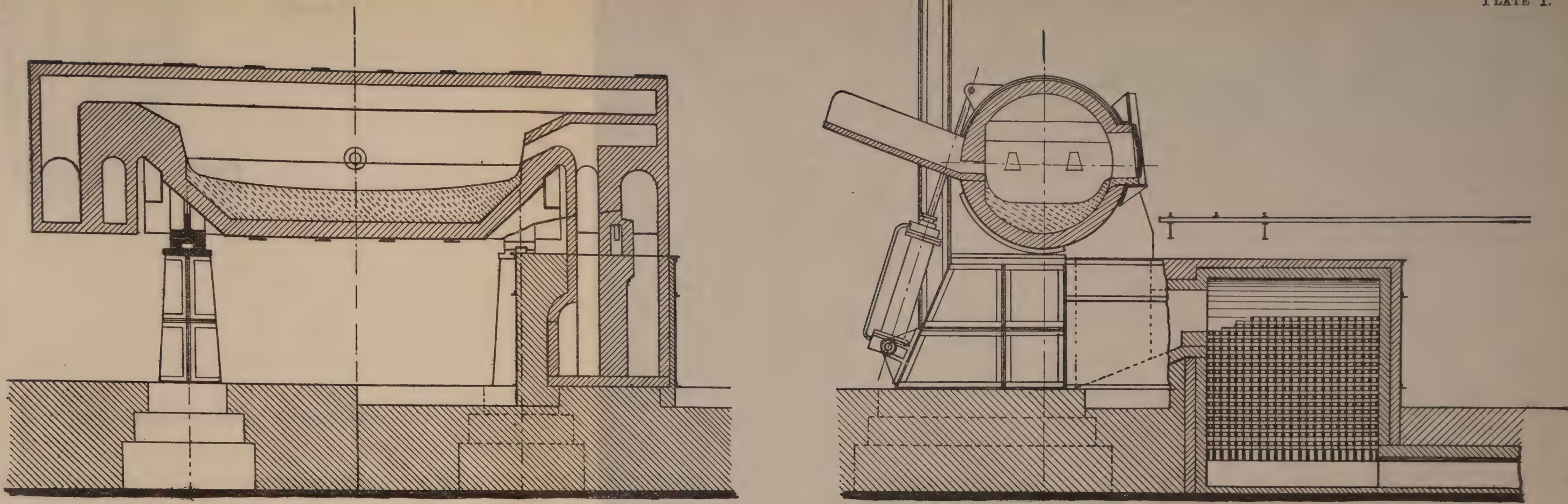


FIG. 7.—1895. Wellman 30-ton Tipping Open-Hearth Furnace.

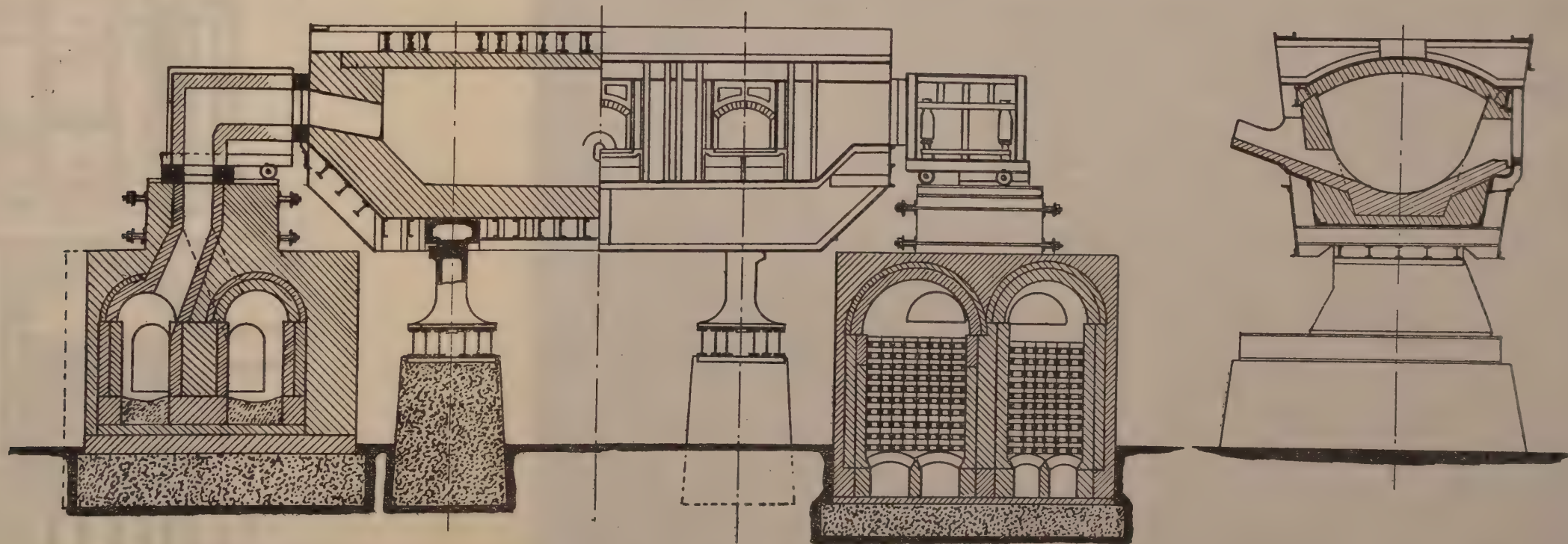


FIG. 8.—1898. Talbot Furnace. Pencoyd. (Tilting.)



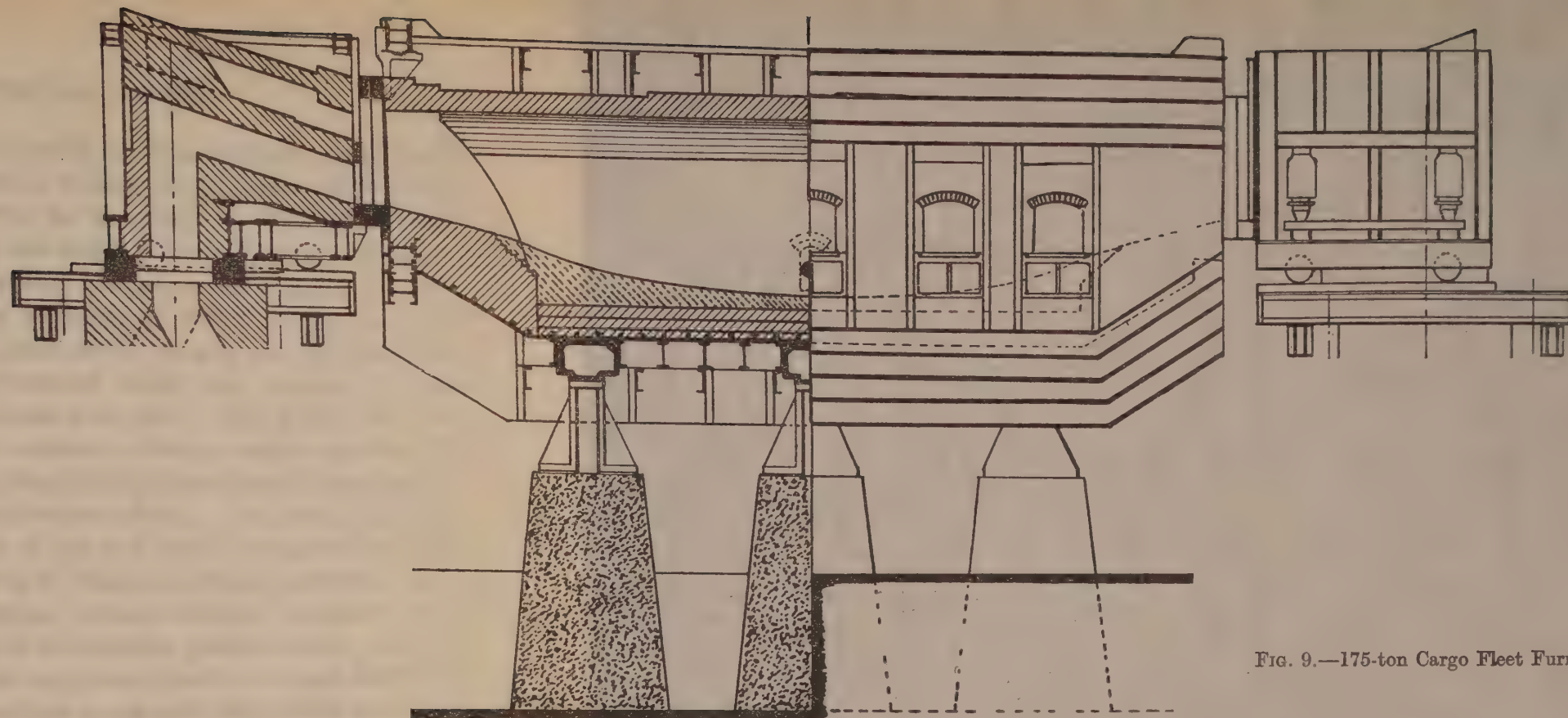


FIG. 9.—175-ton Cargo Fleet Furnace with Open Block.

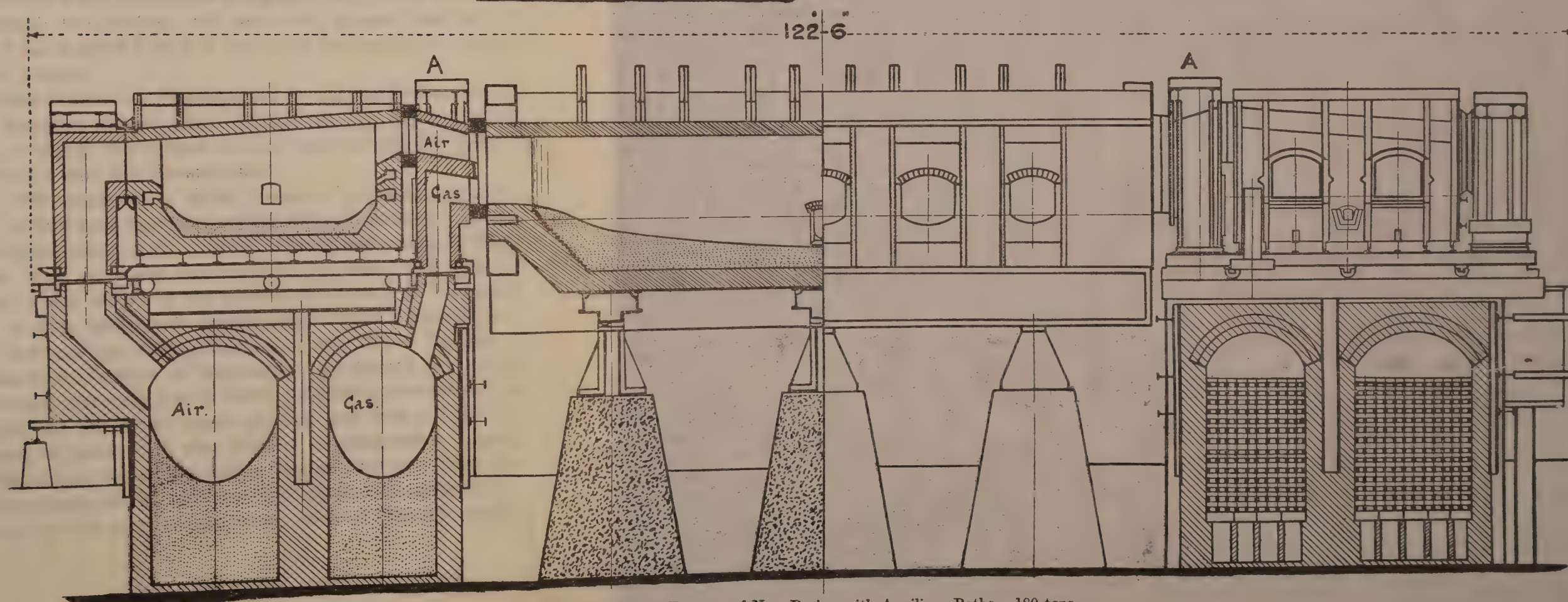


FIG. 10.—Talbot Furnace of New Design with Auxiliary Baths. 180 tons.



process I looked into the merits of these designs, and finally selected Wellman's method of rolling forward instead of tilting centrally, as being the better for the purpose. We did not care for the cylindrical shape of the body of the furnace as built at the Illinois Steelworks, and decided to design the furnace ourselves with flared or sloping sides, as shown in Fig. 8 (Plate I.). As it was decided to have close joints at the ends of the tilting section, movable ports with water-cooled chills and capable of being moved backwards and forwards were used. The flared sides were introduced for the double purpose of more easily repairing the back wall and slag line, and for holding the side walls (especially on the charging side) more firmly when tilting. Also, during slag line and wall repairs, the angle of the wall could be varied by tilting the furnace as desired. Fig. 9 (Plate II.) shows a modern tilting furnace used in the continuous process wherein the ports are all in the movable block. The continuous process being very well known, it is unnecessary to say more about it, except that when first introduced some authorities prophesied dire results as to heats going through the bottom, but since the process has been in operation I have never heard of any heats having broken through the hearth proper.

The other interesting development in the continuous process was the bringing about, when desired, of the carbonic oxide reaction, in which the carbon in the bath is rapidly oxidised simultaneously with the phosphorus.

Since 1899 numbers of tilting furnaces gradually increasing in size up to 250 tons capacity, and of different designs, with and without sloping sides, both centrally tilting and rolling forward, have been built in many steel-making countries, and opinions vary as to which design is the better, the tilting or the rolling furnace, as they both give satisfactory results. Personally, I must say I favour the tilting furnace of, say, 200 to 250 tons as against the fixed furnace of large size. The hearth in a tilting furnace of large capacity can be much more easily controlled, and the facilities for repairs are much greater than with a fixed one, and for ease of removal of slag there is no comparison. Again, another advantage which the tilting furnace has over fixed furnaces of very large size is that it enables the use of smaller ladles; the pouring of the steel is, therefore, effected through smaller

nozzles than is possible where ladles of 150 tons have to be used, and it must be admitted that this factor has an important effect on the satisfactory rolling of the steel.

Of course, there are not many fixed furnaces of even 150 tons capacity, but in large works the tendency is to increase the size. There seems to be now no adequate reason why tilting furnaces of over 300 tons capacity should not be used, especially in large works, and I hope to see them gradually installed.

It is somewhat significant that Holley, in his report of 50 years ago, outlined preliminary refining operations for the acid open-hearth process, and through the period of the development of the basic open-hearth process preliminary refining has been more or less used.

A modification of the basic open-hearth process, known as the Bertrand-Thiel process, was introduced in Germany about 1896. This consisted essentially in the use of two Siemens furnaces working in combination: one was known as the primary furnace, into which the pig iron, oxides, and lime were charged and melted; the other as the secondary furnace, which received the refined liquid metal from the primary furnace. In a later development of the process fluid metal from the blast-furnace was introduced into the primary furnace. By keeping the heat in the primary furnace comparatively low, the phosphorus is very largely removed in this furnace, whilst the carbon remains at about 2 per cent., and this constitutes one of the chief advantages of this modification of the process.

The Hoesch process was another method for effecting the same object; the first slag was separated by tapping the metal into a ladle, and the metal was then returned to the same furnace without the slag.

Monell, in America, charged adequate quantities of oxide of iron and limestone, preheated them, and then poured in liquid blast-furnace metal, refined it, and flowed off the slag.

The so-called "duplexing" method is used largely at times in the United States, in which an acid Bessemer converter is employed to desiliconise and more or less decarbonise metal containing too much phosphorus for acid working. By this means very large outputs have been obtained when working in conjunction with furnaces of 200 tons capacity, an output approaching 5000 tons

per week having been produced from a single furnace. We hear also of outputs of 2000 tons per week per furnace both in Germany and in the United States from large fixed and tilting furnaces, using scrap and liquid metal as a charge. When we think of the weekly outputs of the pioneers in the basic open-hearth, which 45 years ago would be under 100 tons per week per furnace, the present outputs indicate the world's progress.

Fig. 10 (Plate II.) shows a sectional elevation of my new design of open-hearth furnace with auxiliary hearths. The auxiliary hearths are mounted on a frame with wheels, so as to give a longitudinal movement for the double purpose of opening the joint of the furnace when tilting, and also for the rapid removal and exchange when desired of the movable water-cooled throat section A, which contains both the gas and air ports.

As three of them are now at work, perhaps a brief description may not be out of place. Fig. 11 (Plate III.) is a general view of the furnace, and Fig. 12 (Plate IV.) shows details of the movable gas and air ports.

The objects aimed at in the design are to enlarge the hearth area in one unit, to increase output, to decrease repairs, and to reduce costs. A radical departure has been made from the standard furnace in use to-day by the introduction of auxiliary hearths which are used to melt the solid pig iron of the charge when cold pig is used. In furnaces which use a large percentage of scrap, say, 60 per cent., the 40 per cent. of pig iron is melted in the auxiliary hearths, and when required it is tapped and poured into the heated scrap charge in the main hearth. In those works where liquid blast-furnace metal is available, it is poured into the auxiliary hearths, partially refined, the temperature increased, and the metal is then tapped and poured into the main hearth to be worked down into finished steel.

It will be seen in the drawing that, in order to augment the heat available from the main hearth in the auxiliary hearths, gas jets are used when melting or refining liquid pig iron. When in use these gas jets are preferably reversed with the furnace, so that all the gas streams run in the same direction.

Perhaps the idea of mixing and burning a small quantity of gas in the incoming heated air from the regenerator, which further increases its temperature before it burns the gas in the main hearth,

is the most novel idea to be observed in the new design. The amount of carbonic acid in the incoming heated air (due to the combustion of the gas in the auxiliary chamber) is inconsiderable, averaging only about 3 per cent. when producer-gas is used, and we have experienced no difficulty in obtaining combustion of the gas and all the necessary heat required for rapidly working the charge in the main hearth. On the outgoing end gas is used when required in the auxiliary hearth, with or without air as may be necessary.

The results obtained during the past few months are considered satisfactory, as without increasing the area of the centre or main hearth the output has already been increased by at least 50 per cent. in those furnaces which are working the same mixture of cold pig iron and scrap as they were before. The furnace which is being supplied with liquid blast-furnace metal has increased its output by more than 33 per cent., and a greater increase is expected as soon as a larger area in the auxiliary hearths is available. Of course, these auxiliary hearths can be added to large fixed furnaces when there is sufficient space between them.

It is hoped that further experience with this new design of furnace will show that it is a distinct advance upon present types. No doubt, opportunities will be given in the future thoroughly to discuss its merits or criticise its shortcomings. As all the outline drawings shown are upon the same scale, they give some idea of the increase in size which has taken place in basic open-hearth furnaces from the pioneering days of 45 years ago down to the present day.

This address commenced with an extract from a report by Holley half a century ago, which contained a forecast of the possibilities of future steel production. Seeing that the production of steel has risen from $2\frac{3}{4}$ million tons in 1878 to 99 million tons in 1927, I am not bold enough to make a forecast of what the world's consumption may be 50 years hence. It does appear, however, with our present knowledge, as if the basic open-hearth process will produce by far the greatest portion of the world's requirements, as the ores from many of the known deposits in the world yield a pig iron more suitable for this process than for any other.

The process also absorbs vast quantities of miscellaneous



FIG. 11.—New Talbot furnace.



FIG. 12. Details of main boiler and air port.

scrap without it being necessary to select it by analysis. As the uses of steel increase more scrap will be available, and this must be remelted and returned into circulation.

The fact that 64 million tons of steel ingots were produced last year by the basic open-hearth process conclusively proves that the steel is in every way suitable for general engineering purposes, otherwise it would not be accepted by engineers all over the world. The future manufacture of steel can be left with confidence to our successors, as they will have a greater knowledge and larger opportunities than we have had, but they will have new problems to solve. The problem which faced the great inventors of steel—namely, Bessemer, Siemens, and Thomas—was to produce satisfactory qualities in different kinds of plain carbon steel. Sir Robert Hadfield opened up a new era with alloy steels when he demonstrated to the world the valuable properties of his manganese steels.

Other workers have been and are working upon steels containing various alloying elements to produce steels to meet new engineering requirements, and it looks as if in the future there will be greater possibilities of using such steels for many other purposes with every prospect of success. Possibly the greatest problem of all is to prevent, as far as possible, the ravages of corrosion in steel structures, and if this cannot be entirely prevented we must all work to mitigate it as much as is commercially practicable.

Mr. CHARLES M. SCHWAB said that as one who had been a member of the Iron and Steel Institute for thirty-five years, and who was an Honorary Vice-President, but who had not had an opportunity of contributing much to the Institute, he wished to take the present opportunity, in view of the fact that the President had been in America and that American names were frequently mentioned in his Address, of proposing a hearty vote of thanks to the President for the very delightful Address which he had delivered. While in America the President had failed to learn one thing, for the modesty of his Address showed that he had not acquired the American spirit of boastfulness with reference to his work. He had much pleasure in proposing a vote of thanks to his friend, the President, for his delightful Address.

The motion was carried by acclamation.

The PRESIDENT briefly thanked Mr. Schwab for the kind words he had used, and the members for the way in which they had accepted the resolution.

VOTES OF THANKS.

Professor CARPENTER at the conclusion of the meeting said he was sure the members would not wish to separate without thanking the gentlemen who had presided at their deliberations. In the first place, they had to thank their new President, Mr. Benjamin Talbot. Everyone would remember the remarkable Address he had delivered, on account of the interest which attached to an Address in which a man described what was really his life's work.

The members would certainly wish to include in the vote of thanks Mr. Harbord, who had only just vacated the Presidential Chair and who had been called upon to fill the gap created by the President's unavoidable absence at some of the sessions.

The vote of thanks was carried by acclamation.

On the motion of the CHAIRMAN, a very hearty vote of thanks to the President and Council of the Institution of Civil Engineers for their hospitality was carried by acclamation.

ADJOURNED MEETING HELD IN SHEFFIELD,

May 10, 1928.

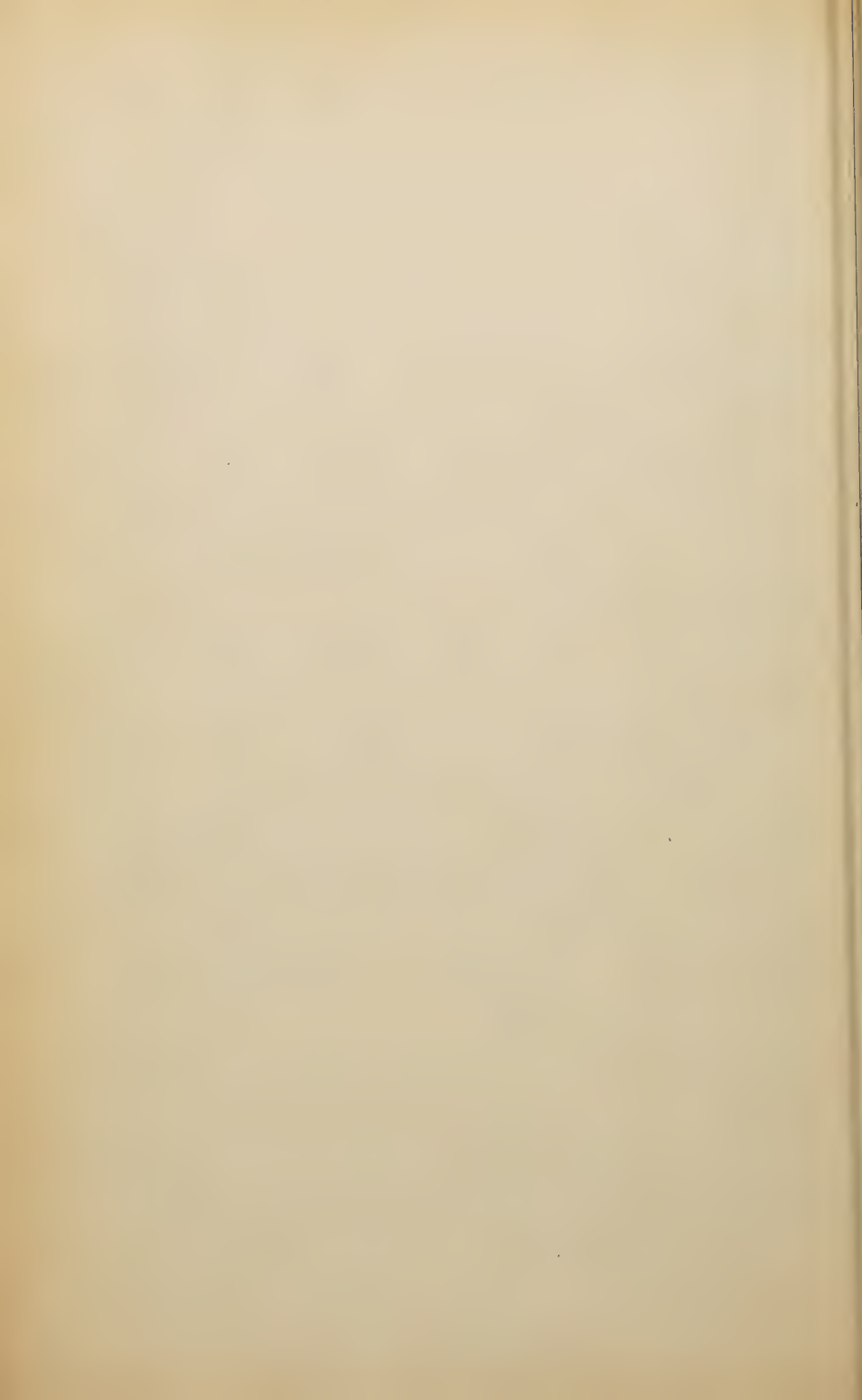
An informal meeting, at which over ninety members and their friends were present, was held in the Mappin Hall of the University of Sheffield on May 10 at 2.30 P.M. It had been hoped that the President (Mr. B. Talbot) would be able to preside, but his plans were upset at the last moment; the immediate Past-President (Mr. Frank W. Harbord, C.B.E.) took his place in the Chair, and was supported by the Lord Mayor of Sheffield (Alderman M. Humberstone) and Sir William Clegg (Chairman of the Committee of the Department of Applied Science). The Lord Mayor extended a welcome to the Institute on behalf of the City of Sheffield and its industries; Sir William Clegg joined in the welcome on behalf of the University. The following papers were presented and discussed:

- (a) "Second Report of the Committee on the Heterogeneity of Steel Ingots."
- (b) J. SWAN: "The Effect of Silicon on Tungsten Magnet Steel."
- (c) J. A. JONES: "The Properties of Nickel Steels, with Special Reference to the Influence of Manganese."

At this point the meeting adjourned for half an hour and partook of tea and light refreshments kindly supplied by the University Authorities. The meeting was then resumed and the two remaining papers on the programme were discussed:

- (d) T. SWINDEN and P. H. JOHNSON: "Chromium Steel Rails."
- (e) W. H. HATFIELD: "Heat-Resisting Steels. Part II.—Mechanical Properties."

The CHAIRMAN (who unfortunately could not conduct the meeting to its close, owing to other appointments) on vacating the Chair expressed the hope that the meeting would be the forerunner of many more such informal meetings all over the country. He also hoped that the local societies, while preserving their own identities, would be able in the future to co-operate more closely with the Iron and Steel Institute.



BLAST-FURNACE DATA AND THEIR CORRELATION.¹

BY EDGAR C. EVANS, F.I.C., AND F. J. BAILEY, M.Sc., D.I.C.
(LONDON).

Summary of Practical Deductions.

1. From a study of over 120 blast-furnace operating results a method has been developed of correlating blast-furnace data on a common basis, which is in agreement with similar methods adopted in reheating furnace practice for the correlation of output and fuel consumption.

2. This method finally shows that, other things being equal, the greater the effective time of contact between the reducing gases and the ore before the hearth is reached, the lower is the fuel consumption.

3. Among the factors influencing effective time of contact are :

- (a) Slow driving of the furnace.
- (b) Preparation of the burden prior to charging.
- (c) Suitable methods of charging.
- (d) Adoption of suitable furnace lines.
- (e) Use of coke of suitable quality.

4. The carbon required for external heat losses in the hearth is of a much higher order than has previously been considered to be the case, and it therefore follows that slow driving of the furnace is the least economical method of obtaining effective time of contact, since the external heat losses per ton of pig iron produced per unit of time are increased proportionately.

5. The carbon required for meeting external heat losses in the hearth zone is inversely proportional to the hearth diameter, so that in furnaces having the same effective time of contact between reducing gases and ore and the same production of iron per sq. ft. of hearth area per hour, small hearths are less economical than large hearths.

¹ Received March 16, 1928.

6. A general study of the results available indicates that furnace practice in different countries has developed on lines covered by economic considerations of the following general character :

- (a) In countries using local ores with a very wide market for pig iron of constant quality, with high labour rates and large capital resources, the tendency has been towards large hearth diameters with moderate rates of driving reckoned as lb. of carbon per sq. ft. of hearth area per hour.
- (b) In countries largely using imported ores of high quality with a market considerably in excess of immediate post-war capacity and with limited capital resources, the necessity of increasing outputs with furnaces of moderate size has resulted in extensive preliminary treatment of the ore with a view to the attainment of very high rates of driving per sq. ft. of hearth area per hour.
- (c) In countries whose market conditions for pig iron are of a constantly varying character, the tendency has been in the direction of furnaces of moderate size operated at moderate rates of driving.

If the furnace efficiency be measured by the extent of preliminary reduction of the materials in the shaft, after due allowance has been made for all factors involved, practice in the various countries is comparatively equal.

7. The quality of the iron, in so far as it is represented by the percentage of silicon, has an important effect on the hearth heat consumption.

8. The influence of dry blast has been investigated, and results indicate not only improved thermal efficiency at the tuyeres, but that a further saving exists, due possibly to an increase in the effective rate of reaction between the gases and ore.

9. Results obtained indicate the necessity of investigation into :

- (a) Improved refractories in blast-furnace practice, to allow of reduction of external cooling losses, with maintenance of suitable furnace lines.
- (b) The influence of the quality of the ore on the efficiency of reduction in the upper portion of the furnace and consequent effect on fuel consumption in the hearth.
- (c) The nature of the influence of moisture and/or hydrogen on blast-furnace reactions.

Introduction.

WHILST statistics of blast-furnace operation from the earliest period for which records are available include the output of the furnace and its fuel consumption, few attempts have been made to correlate rate of driving with fuel consumption.

Probably the first critical analysis of the influence of rate of driving on fuel consumption was made by Sir Lowthian Bell in 1890, in the course of a discussion on a paper submitted to this Institute by J. Gayley.⁽¹⁾ Gayley had described a furnace which was, in the words of Bell, "producing about five times as much iron as we have hitherto been able to from our poorer ore, and about twice as much as has been obtained from our hematite furnaces of like dimensions in England . . . with an expenditure of 16·8 cwt. of coke per ton of iron of a high average quality." Bell suggested that on fundamental grounds the saving in fuel that could be expected from more rapid driving of the furnace must at some stage be counterbalanced by incomplete preparation of materials as they are delivered to the hearth of the furnace. "Therefore," he added, "if the rate you are driving at represents the position of equilibrium I am describing, you will lose heat and waste coke either by driving more slowly or more quickly than you are now doing."

In 1914 H. A. Brassert⁽²⁾ showed that during a period of two years the blast-furnace fuel consumption at the works of the Illinois Steel Co., using Mesabi ores, decreased with increase in output, the relationship between output and fuel consumption being clearly shown in the reproduction of the curve submitted by Brassert (Fig. 1).

J. E. Johnson⁽³⁾ (*loc. cit.*, p. 303), however, points out that the effect of the rate of driving on fuel consumption is complicated. Whilst, on the one hand, there are heat losses for radiation, cooling water, &c., which are irrespective of the rate of driving, so that the greater the output of the furnace the lower the fuel consumption, "on the other hand, a sufficient allowance of time for the completest possible reduction of the ore in each zone is an indispensable condition for maximum economy," and therefore if the rate of driving were so great that this could not be effected, increase in fuel consumption would result. Thus the views of

Johnson are in close agreement with those advanced 40 years ago by Bell.

Reviewing the whole of the evidence, and after a detailed

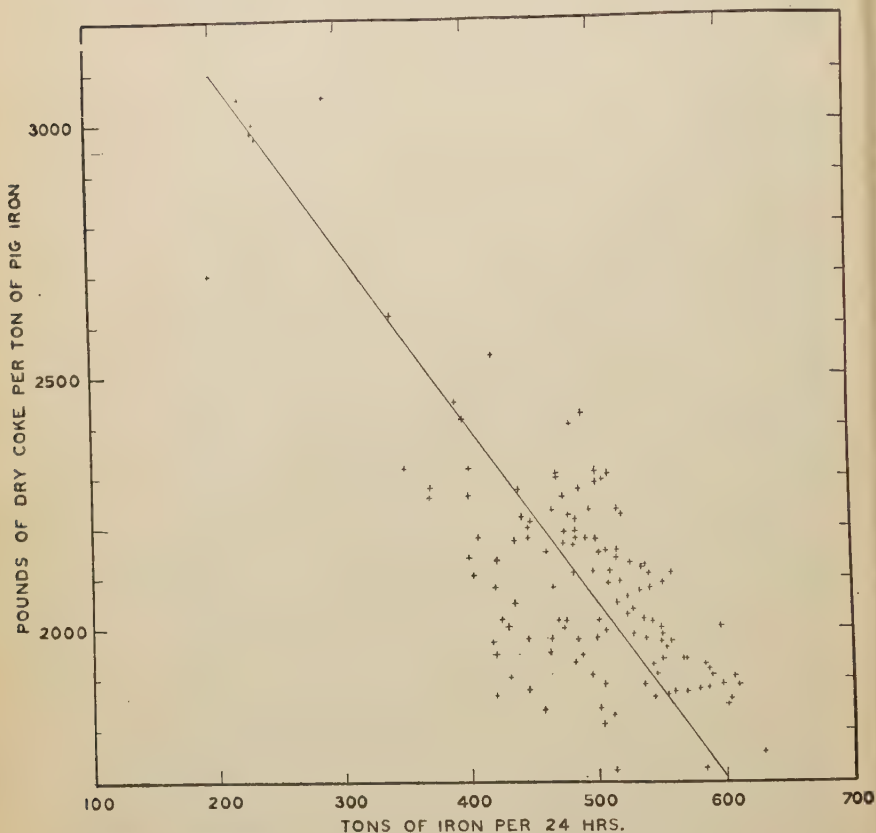


FIG. 1.—Relation of Iron made per Day to the Coke Consumption. (Brassert.)

investigation of a number of operating records, the authors are of opinion that, whilst outputs have increased considerably beyond those suggested as being possible when Sir Lowthian Bell made the above pronouncement, the returns available from rapidly driving furnaces demonstrate the fundamental truth of Bell's conception, that in any given furnace there is a definite optimum rate of driving, governed partly by the constant external heat

losses of the furnace and partly by the condition of preparation of the materials reaching the hearth of the furnace.

The method of investigating the question has been of a statistical character. A large number of operating records have been examined, which include, as far as possible, the essential factors involved, the less important factors being left out of consideration in the earlier stages and attention concentrated on those that were obviously the most important. In this method of investigation it was considered desirable to leave for consideration at a later stage the complex chemical phenomena of blast-furnace practice, which as Johnson points out "is not a chemistry of definite atomic proportions, but is a chemistry of infinitely varying balances among conflicting tendencies," and to consider at the outset the thermal viewpoint only.

Relation between Output and Fuel Consumption.

In this connection an examination of the influence of the output of the furnace on fuel consumption is of importance, as one of the factors—external cooling loss by radiation, &c.—remains constant, whatever the output. Such a method of examination has proved of considerable service in other fields of fuel technology.

In boiler practice, correlation of output and fuel consumption, by working on the well-known Parsons' line, has proved to be an easily applied method of control of operating conditions.

Continuous reheating furnace practice presents, perhaps, a more interesting field for comparison, as conditions are to some extent more analogous with those in the blast-furnace than is the case with a boiler. There is a continuous flow of stock from one end of the furnace to the other, directly heated by furnace gases passing from the hearth (where the final preparation of the material takes place) to the stack, and a definite correlation has been shown to exist between output and fuel consumption. This correlation has been investigated in detail by a number of Continental observers and independently by H. C. Armstrong, and utilised in works practice for the control of operating furnaces.⁽⁴⁾

It has been shown that, in order to operate a furnace satisfactorily, heat must be generated at such a rate that a constant predetermined mean temperature is maintained in the hearth.

It is obvious that a considerable amount of fuel must be consumed to maintain this temperature, even when the furnace is empty, in order to make good the radiation and other external cooling losses. Moreover, in accordance with the well-known laws of heat transfer, the total heat which must be brought into the hearth zone must be very largely in excess of the actual external heat losses. In customary reheating practice with preheating of the air, some three to four times as much fuel is required as is necessary to supply the actual B.th.u.'s lost by radiation and other external cooling losses.

This fuel is a standing charge on the requirements of the furnace, and will be a constant per hour irrespective of the loading and throughput of the furnace. Each successive pound of stock heated per hour will necessitate the burning of a further proportionate quantity of fuel per hour, so that the weight of fuel burnt per unit of time for this purpose is directly proportional to the weight of throughput per hour.

Characteristic Furnace Curves.—Fig. 2 illustrates a typical curve developed on this basis, which may be represented by the general equation :

$$C = R + xI \quad . \quad . \quad . \quad . \quad . \quad (1)$$

where C = lb. of fuel burnt per unit of time ;

R = a constant representing the lb. of fuel per unit of time to make good the external heat losses ;

x = lb. of fuel required per lb. of stock ;

I = lb. of stock throughput per unit of time.

An examination of the results obtained by Armstrong and others shows that this equation is not merely theoretical, but is a true record of furnace performance, even in the case of hand-fired reheating furnaces, where widely varying conditions are introduced by the human element, and, if it applies under those conditions, it is reasonable to assume that the application of the method can be extended to the case of blast-furnaces. It must be noted, however, that the formula applies only to the hearth of the furnace, and that the sum total of the effects of preheating of gas, stock, and so on, are included in the factor x .

The same applies in the application of the formula to blast-furnace practice, but conditions are more complex and adjustment of the equation is necessary in view of the additional

factors involved. In blast-furnaces, the hearth zone must be considered to be a hypothetical region, the extent of which cannot be precisely defined, but may possibly be controlled by the limits of direct radiation from the zone of combustion. As a first approximation it can be assumed that this zone is constant in

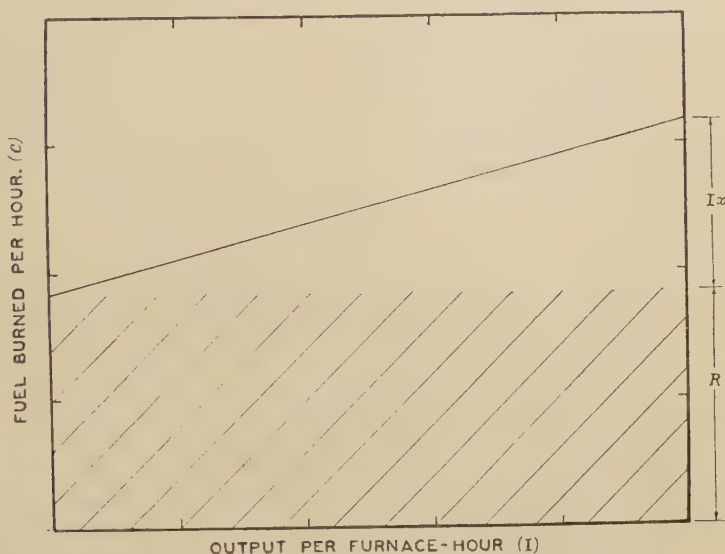


FIG. 2.—Characteristic Furnace Curve. (Continuous reheating furnace.)

height for operating coke furnaces over a wide range of rate of blowing. In this zone heat is supplied :

- (1) by complete combustion of carbon to carbon monoxide, and
- (2) by the sensible heat in the blast.

Since the end product of combustion is wholly carbon monoxide, each lb. of carbon burnt at the tuyeres necessitates exactly the same amount of air, and the additional heat, by raising the temperature of this air, can be calculated directly and expressed as a proportion of the carbon burnt. As in the case of the reheating furnace, the external heat loss is a fixed standing charge which must be made good irrespective of the throughput of the furnace.

The blast-furnace, however, differs from the reheating furnace

in that the stock heated consists of two products—iron and slag—the respective heat requirements of which are of a different order, and which are produced in variable proportions to each other. The heat requirements for the stock, then, must be subdivided into iron and slag requirements.

Further, in order to allow of a definite comparison being drawn between furnaces of varying hearth diameters, it is convenient to adopt the general convention of expressing the figures in the formula as lb. of material per sq. ft. of hearth area per hour.

Characteristic Blast-Furnace Curves.—Allowing, then, for the varying thermal requirements of the iron and slag, the general formula (1) becomes :

$$C_1 + C_2 = R + XI + YS \quad . \quad . \quad . \quad . \quad (2)$$

where C_1 = lb. of carbon gasified at tuyeres per sq. ft. of hearth area per hour ;

C_2 = sensible heat introduced with the blast, reckoned as lb. of carbon (burnt to CO) per sq. ft. of hearth area per hour ;

R = heat requirements per sq. ft. of hearth area per hour to make good the external loss ;

X = the heat requirements per lb. of iron made ;

I = lb. of iron made per sq. ft. of hearth area per hour ;

Y = heat requirements per lb. of slag made ;

S = lb. of slag made per sq. ft. of hearth area per hour.

Limiting consideration of this expression to one furnace for the time being, it is desirable to see how many of the factors can be directly calculated. Provided the gas analysis is accurately known, the factor C_1 —carbon gasified at the tuyeres—can be calculated from the total carbon gasified in the furnace by any of the customary methods suggested by Richards, Johnson, Howland, &c. ; Howland's method was adopted, as shown in Appendix I. Owing to the extreme difficulty of obtaining accurate analyses for the necessary period of time, it has been assumed, as a first approximation, that sufficient accuracy is obtained by taking the carbon in the coke used other than at the tuyeres as a constant at 350 lb. per ton of pig iron. The carbon burnt at the tuyeres, therefore, has been taken throughout the following notes as the carbon charged in the coke less 350 lb.

The heat introduced by the blast, expressed in its carbon equivalent, may be calculated from a knowledge of the temperature and the specific heat of the air at the temperature of the blast. Figures quoted by various authorities for the specific heat of air at high temperatures differ somewhat, but by averaging the

available data submitted by recognised authorities it is estimated that for every lb. of carbon burnt at the tuyeres, 1·386 B.th.u. are brought in per 1° F. rise of blast temperature. This is equivalent to 0·000317 lb. of carbon burnt to carbon monoxide per lb. of carbon burnt per $^{\circ}$ F. of blast temperature. For simplicity in

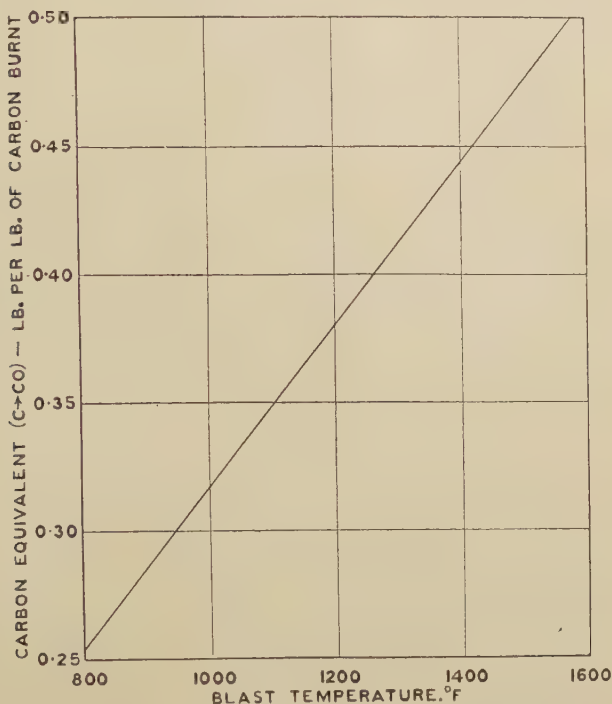


FIG. 3.—Sensible Heat in Blast, reckoned as lb. of Carbon per lb. of Carbon burnt at the Tuyeres.

calculation, the datum has been taken at 0° F. instead of at mean air temperature, so that the carbon equivalent per lb. of carbon burnt at the tuyeres of the sensible heat of the blast may be obtained by multiplying the blast temperature ($^{\circ}$ F.) by 0·000317, or directly from Fig. 3.

The quantity of moisture introduced with the blast varies, and is not generally specified in the majority of blast-furnace returns, so that this factor is left for consideration at a later stage,

the calculations being based on the assumption that dry air was used.

The heat production side of the equation, then, is easily calculated, but the heat requirements on the other side of the equation are difficult to determine. It can be assumed that the external heat loss per unit of time from any individual furnace will remain substantially constant over a considerable period, but the actual amount is difficult to determine, and it is still more difficult to ascertain how much carbon must be burnt in the hearth in any individual furnace to meet these losses.

The same applies to the heat requirements of the iron and slag. The quantities of these products produced per sq. ft. of hearth area per hour are directly calculable from the blast-furnace returns, but their heat requirements reckoned as lb. of carbon burnt have not previously been determined. Further, the problems involved are complicated by the fact that a proportion of the heat leaving the hearth zone under consideration as sensible heat in the gas is brought back as sensible heat in the stock entering the zone. Possibly the simplest method of calculation is to assume that the iron and slag require in the hearth zone a quantity of heat additional to that brought in as sensible heat from the shaft, and to include in the factors X and Y the net carbon to meet these additional requirements.

Statistical Application to Operating Returns.—Apart entirely from the definite quantities of heat required in the hearth to bring the slag and metal up to running temperatures, there are a number of other factors of unknown or little-known value, and neither these nor the factor for external heat loss can be calculated from returns of any one furnace. The three principal unknowns, however, may be estimated as average values from a large number of furnace returns, using the customary methods of statistical analysis.

It is necessary at the outset to eliminate the variables due to different hearth diameters, but this is simplified by the fact that the observers of the American Bureau of Mines have shown that over a very wide range of operation, including furnaces of different size making different qualities of iron from different ores and producing slags of different character, the mean operating hearth temperatures are approximately constant.⁽⁵⁾ Thus the metal

temperature in all the cases examined by these authorities varies $\pm 50^{\circ}$ C. ($\pm 90^{\circ}$ F.) on either side of 1450° C. (2642° F.), and the slag temperature $\pm 100^{\circ}$ C. (180° F.) on either side of 1500° C. (2732° F.). If a thickness of refractory of the furnace walls which is small compared with the hearth diameter and a constant internal temperature of the various furnaces be assumed, the heat loss from the hearth zone may be represented as necessitating the combustion of

$$\frac{K}{D} \text{ lb. of carbon per sq. ft. of hearth area.}$$

Where K = a constant, and
 D = hearth diameter in feet.

(As will be seen later some qualifications will be necessary, owing to differences in amounts of cooling water for tuyeres, boshes, &c., used per unit of time in different furnaces, but a study of the furnace records available will give by this method an average figure which can be adjusted subsequently for individual conditions.)

The equation therefore becomes :

$$C_1 + C_2 = \frac{K}{D} + XI + YS \quad . \quad . \quad . \quad . \quad (3)$$

in which form it is applicable to all hearth diameters.

In the subsequent notes, hearth heat requirements for iron and slag as calculated from the above equation are expressed as the "iron factor" and the "slag factor" respectively.

Over 120 reasonably reliable records of blast-furnace operation were available as a basis of investigation of the actual values of the factors K , X , and Y , and by suitable graphical and statistical methods, after the elimination by the method of trial and error of values which were obviously incorrect, mean values were obtained for the factors involved, namely, $K = 500$, $X = 0.56$, and $Y = 0.28$. The average equation, therefore, for the whole of the furnaces examined becomes :

$$C_1 + C_2 = \frac{500}{D} + 0.56I + 0.28S \quad . \quad . \quad . \quad . \quad (4)$$

This equation is, of course, only a first approximation, and is subject to revision whenever better methods of investigation and/or more accurate blast-furnace records become available. The equation represents a fair average over the full range of

furnaces examined, with widely varying hearth diameters, making different qualities of pig iron with coke consumptions varying from less than 17 cwt. to over 33 cwt., and operating in a number of different countries.

The order of accuracy of the factors estimated can perhaps be gathered from the fact that in 50 per cent. of the cases examined coke consumptions calculated from these factors come within ± 5 per cent. of the actual amounts used in practical operation, and in 80 per cent. of the cases within ± 10 per cent., so that the equation can be taken as representing a reasonable average for customary blast-furnace practice. It must not, however, be assumed to represent more than an average value, as the results of any individual furnace, and sometimes even of a whole district, may be influenced by factors which are not common to all the furnaces examined, and results in such cases might show a distinct divergence from the average.

This fact proved to be the case at an early stage of the investigation, and in some cases, where a sufficient number of records were available of furnaces varying widely from the average but having one factor in common, it was found possible, not only to account for the divergence, but to obtain a numerical expression for the principal new factor involved. For example, the production of foundry iron of low sulphur content is generally accompanied by high fuel consumption, and the analysis of records of furnaces making foundry iron gave results above the average value.

Quality of Pig Iron and Hearth Reduction.—The additional slag produced to maintain a low sulphur content in the pig had already been allowed for, and assuming that the hearth temperatures of all furnaces are substantially the same, whatever quality of iron they produce, the high values obtained would only be accounted for either by :

- (1) varying heat requirements per unit weight of different slags, or
- (2) varying heat requirements per unit weight of different qualities of iron.

No information appears to be available as to the varying heat requirements *in the hearth* of different qualities of slag, and no

simple relationship could be discovered in the course of extensive investigations; there seems every reason to believe that any variations which exist in the hearth heat requirements of different slags are not of a sufficiently large order to affect appreciably the calculations at this stage. The slag factor, therefore, has been assumed to be sufficiently constant to be taken as 0.28, whatever the quality of the iron produced.

In the case of the iron factor X , however, correlation of the basic equation with practical results could only be obtained by assuming that this differed widely with different qualities of iron. The most important constituent in the iron, from a metallurgical point of view, is probably sulphur, but a low sulphur content would be allowed for in the slag factor. Of the others, silicon, manganese, and phosphorus, silicon requires the greatest proportional amount of heat for reduction, and, as it is generally assumed that nearly the whole of the silicon is reduced in the hearth zone, it might be expected to have an important relationship to the hearth fuel consumption. This proved to be the case. Not only were foundry irons found to give results which were widely divergent from the average values obtained from the equation, but it was found that there seemed to be a definite relationship between the percentage of silicon in the pig iron and the X factor. The curve in Fig. 4 shows the relationship between the calculated iron factor and the percentage of silicon in the iron made. It will be seen that the points on the graph are grouped in a band about a mean line which can be represented by the simple equation :

$$X = A + 0.12 \times \% \text{ Si} \quad . \quad . \quad . \quad . \quad (5)$$

Fig. 5 is a continuation of this curve plotted to show one example of iron containing 10 per cent. of silicon, indicating that the value is a very close approximation.

The average value for A from equation (5) is 0.4, so that the average equation after allowing for silicon content in the pig becomes—

$$C_1 + C_2 = \frac{500}{D} + [0.4 + (0.12 \times \% \text{ Si})] \times I + 0.28S \quad . \quad . \quad . \quad (6)$$

Time in the Furnace and Hearth Reduction.—Whilst 0.4 is an average value, it varies considerably, and there are a number of

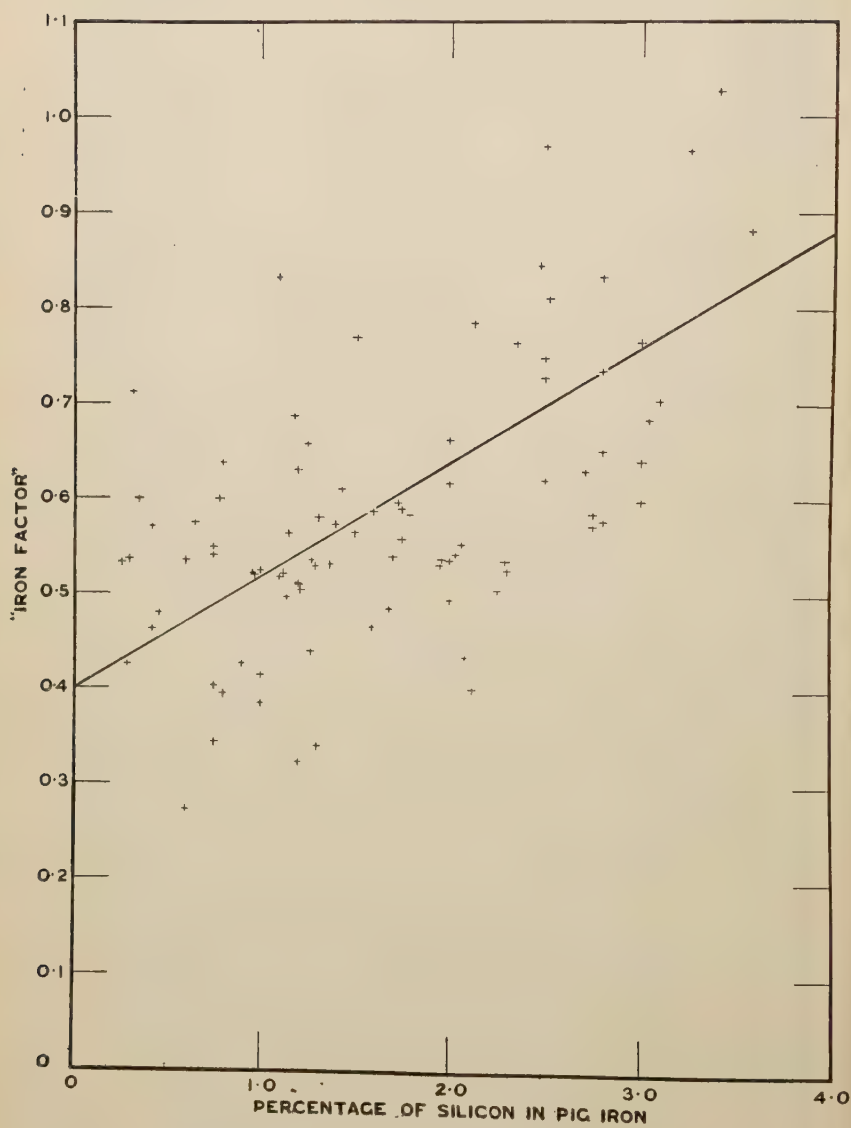


FIG. 4.—The Relationship between the "Iron Factor" and the Percentage of Silicon.

factors involved which have not been treated in the preceding analysis.

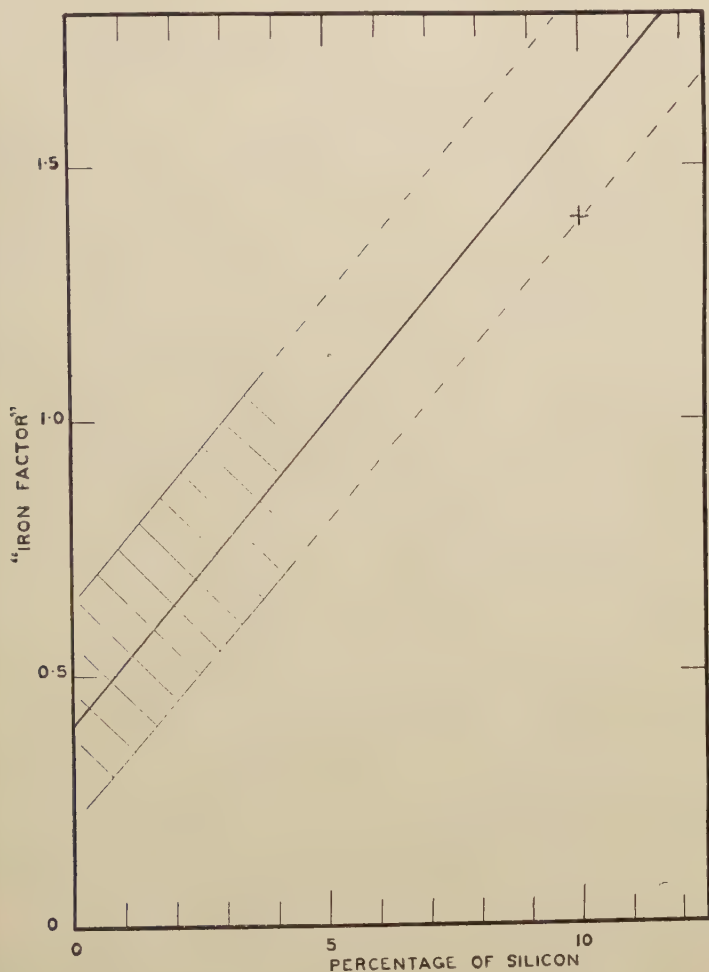


FIG. 5.—The Relationship between the "Iron Factor" and the Percentage of Silicon. The hatched portion represents the limits with normal blast-furnace operation. + represents a figure for ferro-silicon manufacture.

It is obvious, however, that the value of A , or in general the value of the X factor, is an expression of the amount of hearth

reduction. Since the days of Sir Lowthian Bell it has been realised that a proportion of the reduction takes place in the hearth zone, but for a long period it was assumed that a neutral zone existed between the hearth reduction zone and the upper reducing zone of the furnace, and owing to this conception the full significance of hearth reduction was not fully realised.

Joseph, Royster, and Kinney⁽⁶⁾ have shown by careful deduction from gas analyses on an operating blast-furnace that the reduction of the ore is gradual and apparently continuous down to the hearth. This must not be taken as assuming that the velocity of reduction of the ore is constant throughout its passage through the furnace. In point of fact curves indicating the proportionate reduction in different zones obtained by the Bureau of Mines observers indicate that there are two zones where velocity of reduction is highest—namely, the upper portion of the shaft and the hearth, the velocity slowing down in intermediate portions of the furnace, but with no evident break in the reduction curve. All the reduction not effected in the preparation of the stock in its descent down the shaft must take place in the hearth zone, whilst the extent of preparation or reduction of the stock in the shaft of the furnace must ultimately be directly proportional to the time of contact of the gas stream and the stock. This time of contact, assuming uniform distribution of the gas in the furnace (a condition of vital importance, which is extremely difficult to attain in practical operation), will be dependent fundamentally on the time taken by the stock to reach the hearth zone and on the mean surface area of the iron ore exposed to the action of the gas, but is only to a small extent dependent on the quantity of gas generated. If, for example, the quantity of gas be doubled, the gas velocity will be doubled, and the time of contact per unit quantity of gas will be halved, the actual time of contact between gas and ore being, therefore, practically independent of the quantity of gas generated in the hearth. The mean surface area of the ore exposed to the action of the gas is dependent upon the size, shape, and character of the surface of the ore, and with different ores wide variations would be expected, which for the present cannot be correlated, except in a very general way. It is, however, possible to estimate the remaining factor, the time taken for the stock to reach the tuyeres,

and this factor may be expected to be to a great extent indicative of the time of contact in customary furnace practice, where similar ores are being used.

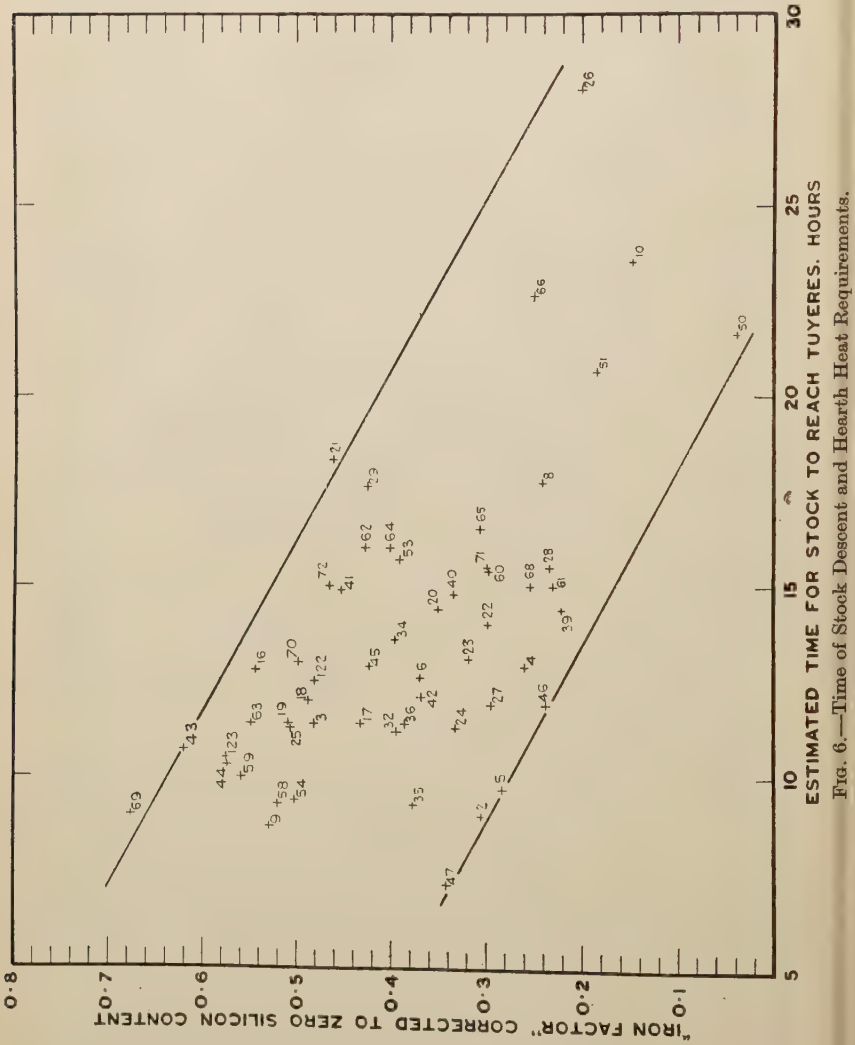
The method of calculating the time during which the material is in the furnace is shown in Appendix II. In all cases, where sufficient data were available, due allowance was made for differences in the apparent specific gravity of the various constituents of the stock. The general curve obtained is given in Fig. 6, and it is evident that there is a definite relationship between the length of time the materials are in the furnace and the iron factor; the longer the material is in the furnace the lower the iron factor, the average mean value of the iron factor falling at the rate of approximately 0.022 per hour that the material is in the furnace.

Optimum Rate of Driving.—The mathematical correlation of data of operating furnace practice makes it clearly evident that Bell's suggestion made as far back as 1890, that the rate of driving in a furnace would be limited at some stage or other by inadequate preparation (or reduction) of the materials in the shaft, is fully confirmed. There are evidently two counterbalancing factors: an increased rate of driving would result in a lower fuel consumption, due to reduced external heating losses per ton for the increased iron produced at higher rates of driving, but, in opposition to this, the faster the rate of driving the less would be the time of contact of the materials, the higher would be the iron factor X , and the fuel consumption.

There must therefore be, as Bell suggested, an optimum rate of driving in customary commercial furnaces; but this general statement needs to be qualified owing to the limitations which accompany operating conditions. There is in customary practice extreme difficulty in maintaining at all times absolutely uniform distribution of the gas throughout the charge, with consequent complete and intimate contact of every particle of ore with the reducing gas throughout its passage through the furnace.

Any method available for improving the uniformity of distribution of the reducing gas would essentially have the effect of increasing the time of contact of the gas and ore, and would therefore result in a reduced iron factor. The practical methods of obtaining such uniform distribution are well known, but

conditions differ so much in different furnaces that a statistical method of general application is difficult to employ. Comparisons



of practice in districts where certain features are common to all furnaces with average practice may be of service in indicating more closely the special factors differentiating the practice in these

districts from the average, but this is frequently only of limited application, and it may sometimes be necessary to consider one furnace only, and to ascertain from a study of operating results under different conditions the effect of the variables involved.

Considerable further study, both of a larger number of operating records and of individual furnace practice, working under different conditions, is therefore desirable, but some attempt may be made with the data available to indicate, if not to evaluate, the various additional factors that have not been dealt with. Among these are :

- (1) Coke quality,
- (2) Character or reducibility of ore,
- (3) Distribution of burden,
- (4) Sizing of materials,
- (5) Furnace lines.

These are not entered in their relative order of importance, which at the present stage of investigation may be difficult to determine, but in an order which allows of the more precise presentation of the data available. All these factors have one feature in common : they involve an alteration in the effective time of contact between gas and ore, but in every case complications occur, owing to variations in the rate of driving which may result. The effect of coke quality may perhaps be taken as an example.

Influence of Coke Quality.

An important physical quality of coke for blast-furnace use is its resistance to disintegration under blast-furnace conditions.

Results quoted by one of the authors ⁽⁷⁾ have shown that in one case the elimination of coke breeze below $1\frac{1}{2}$ -in. mesh resulted in an increase of output of $16\frac{1}{2}$ per cent., and a reduction of coke consumption per ton of pig iron of 7.85 per cent. This could be partly explained by the improved distribution of the reducing gas in the furnace after the elimination of the breeze, with consequent increase in the effective time of contact of gas and ore, and a reduced iron factor. Such an increase in effective time of contact might be expected in all cases where the physical quality

of coke is improved. In all examples of reduced fuel consumption submitted to the authors resulting from the use of a better coke, a common feature has been an increase in output accompanied by reduced blast pressure. In this connection J. E. Johnson⁽³⁾ (*loc. cit.*, p. 109) has developed the following formula, correlating blast pressure, volume of air blown, and resistance to blast offered by the charge :

$$P_1^2 - P_2^2 = K \frac{W^2}{D^4} H,$$

where P_1 = absolute pressure at the tuyere zone ;

P_2 = " " " " stock line ;

W = air blown per minute under atmospheric conditions ;

D = furnace diameter ;

H = furnace height ;

and K = constant (from experience in cases quoted by Johnson = 0.0008).

In its simplest form this formula can be expressed as :

$$V = \frac{P}{R}$$

where V = volume of air per unit of time ;

P = pressure at the tuyeres ;

and R = resistance of stock to blast.

With constant-pressure blowing, if the resistance to the blast were reduced, the volume of air per minute would increase, with a consequent increased rate of combustion at the tuyeres, increased output, and reduced fuel. With constant-volume blowing, the furnace manager would take advantage of the reduced pressure by increasing his burden, with a consequent increased output, and reduced fuel per ton of product.

As coke occupies about 60 per cent. of the volume of the blast-furnace, an increase in coke fines of, say, 5 per cent. would result in a serious increase in channelling, a reduction in the effective time of contact between the gas and ore, and an increased iron factor.

The effect, therefore, of improved physical quality of coke would be :

- (1) Increased output, with consequent reduced fuel, the effect of which, however, *would be diminished by*
- (2) decreased time of contact, due to the more rapid descent of the burden, whilst this would be *counterbalanced possibly by*

- (3) increased *efficiency* of contact due to reduced channelling and better distribution of the reducing gas.

In addition, it is necessary to take into consideration other factors, such as alteration in slag volume due to coke ash and sulphur, and also the alteration in the fixed carbon due to variations in ash, sulphur, and moisture.

In some cases, where improvement in the chemical quality of the coke is also accompanied by improved physical quality, the sum total of all these factors may be considerable, and the fuel saving effected may be very much greater than could be calculated on the reduced requirements for the slag and the increase in fixed carbon only; but other factors are frequently changed, and sufficient details are in most cases not available to allow of a complete analysis of their effects. This is particularly the case in Great Britain, where coke consignments to blast-furnaces are only rarely large enough to permit of a trial being made over a period long enough to allow of a complete analysis of the results.

Particulars have been published by C. S. Gill⁽⁸⁾ of results obtained with cokes of varying ash content at the works of the Consett Iron Co., Ltd., and, with the assistance of supplementary data, the more detailed analysis given in Table I. has been prepared.

TABLE I.—*Operating Data with High and Low Ash Cokes.*

	High-Ash Coke. 12·5% Ash.	Low-Ash Coke. 8·75% Ash.
Iron produced per sq. ft. of hearth per hour. Lb.	160·5	201·5
Slag produced per sq. ft. of hearth per hour. Lb.	87·4	89·8
Carbon burnt at tuyeres per sq. ft. hearth per hour. Lb.	123·4	150·8
Iron factor <i>X</i>	0·606	0·686
Iron factor corrected for silicon <i>A</i>	0·480	0·574
Carbon per sq. ft. hearth per hour burnt to meet external cooling losses <i>R</i> . Lb.	50	50
Calculated time of material in furnace. Hrs.	12½	10½

A definite increase of about 23 per cent. in the rate of combustion of carbon at the tuyeres occurred; the preceding analysis suggests that this was due to reduced resistance of the stock to

the blast, which was confirmed by observation during the tests. With a very similar burden in both cases, this was accompanied by a correspondingly increased iron production of just over 25 per cent. As the carbon burnt at the tuyeres per hour to meet external heat losses (R) was exactly the same in both cases, the total carbon requirements per unit of iron were reduced with the higher production, but this effect was counterbalanced by a decreased time of passage of the material through the furnace, with a consequent increase in the iron factor (corrected for silicon) from 0.48 to 0.574. The two results plotted in Fig. 6 show a marked conformity with the average curve obtained from a general study of results available.

Both cokes used in the tests were of similar physical quality, and the differences would probably have been greater had the improvement in chemical characteristics been accompanied by improved physical structure.

The results, however, made on an extensive scale with an accompanying detailed investigation of all the factors involved, offer considerable support to the hypothesis put forward as a result of general statistical investigation.

It is evident that the influence of coke quality is complex. Essentially, as was recently pointed out by one of the authors,⁽⁹⁾ the physical properties of coke required for furnace use are those which allow of the most complete preparation or reduction of the materials in the shaft consistent with a maximum rate of driving, but, as increased rate of driving is accompanied by reduced time of contact, it is of the utmost importance that the coke should be of such a quality as to maintain at the optimum driving rate the most uniform distribution of gas in the furnace, which is only possible provided fines be eliminated to the fullest possible extent and uniformity of coke size be maintained.

Fig. 6 indicates to some extent the effect of the quality of the coke on the distribution of gas and ore, or, in other words, on the time of contact. In a very general way it can be stated that results from districts in which coke of only moderate quality is used show a tendency towards a higher iron factor than those from districts where cokes of good quality are available. There are, however, so many factors of a somewhat similar order of importance, and the results examined are, as yet, so comparatively

few in number, that there are many exceptions, and no well-defined conclusions can be drawn by general statistical study.

Influence of Character or Reducibility of Ore.

The question is still further complicated by an examination of a series of results of furnace practice in an important producing area (District A).

The iron factors for these furnaces, after correcting for silicon, are plotted against times of passage of the material through the

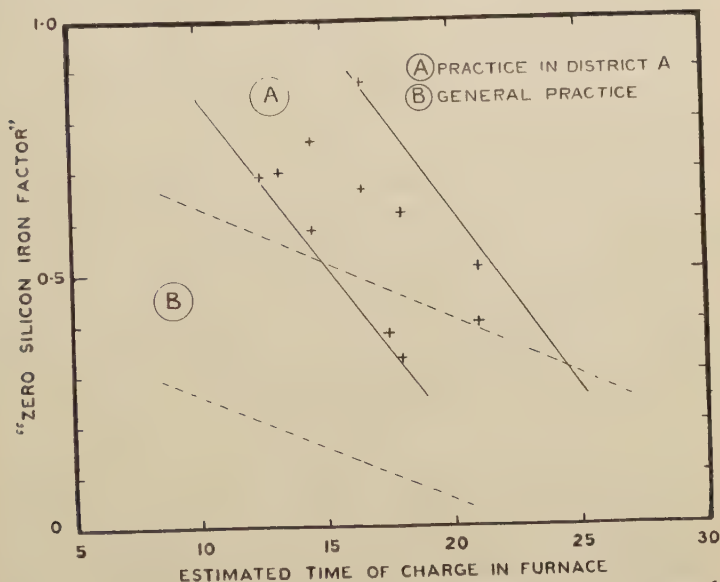


FIG. 7.—Comparison of Practice in District A with General Blast-Furnace Practice.

furnace in Fig. 7; it will be seen that results in general are appreciably higher than those of practice in other areas.

Many of these furnaces are using coke of excellent physical and chemical quality, so that the coke factor can to some extent be eliminated. The question therefore arises whether the high values in these areas are due to a factor—ore quality—common to all the furnaces. At the moment this question cannot be answered,

but the results indicate the necessity for the investigation of ores of this type along the lines that are now being pursued by Professor W. A. Bone and his collaborators. Results of this research already indicate that between certain well-defined limits of temperature carbon deposition occurs to a most important extent. It has been suggested that this reaction is favourable to the operation of the blast-furnace, but, on the other hand, such deposition may be accompanied by physical changes in the ore which might affect the uniformity of distribution of the gas in its passage through the zone at which this reaction occurs. If, however, this effect can be adequately controlled, by suitable burdening or correct furnace lines, the reaction should be beneficial. In any case, it profoundly influences blast-furnace phenomena, and it is desirable that the behaviour of different ores at the temperatures at which it occurs, and also at the higher temperatures beyond which the reaction does not proceed, should be determined. Further, little is known of the rate of reaction between the reducing gas and the ore at temperatures between 600° and 1500° C., and it is possible that the exploration of reactions between the reducing gas and the ore between these temperatures may throw further light on the undoubted differences between the fuel consumptions required for smelting different types of ore which are experienced in practice.

Distribution of Burden.

Whilst variations in practice, as the result of altering conditions of distribution of burden, are well known to practical blast-furnace managers, sufficient data are not available to allow of their discussion from a statistical standpoint, and the same applies to the sizing of materials. It is obvious, however, that correct sizing and grading of the materials in the furnace should assist in securing more uniform distribution of gas and ore, and, therefore, increased effective time of contact. In this connection A. Wagener⁽¹⁰⁾ recently pointed out that the crushing of ore had resulted in increased output and economy in practice in Luxemburg and Lorraine.

Crushing of the ore would increase the area of surface exposed to the reducing gas, and would thus have the same effect as

increased time of contact. Possibly the same reason might account for the exceptionally low iron factors associated with certain furnaces smelting fine ores. The area of surface offered to the gas by such ores must be considerably in excess of that where larger-sized material is used, and, provided suitable furnace lines are used which would not allow of too premature descent of unreduced material to the hearth, fineness of ore up to a point might, if the furnace be not overdriven, result in a low iron factor with consequent fuel economy.

The importance of grading and preliminary treatment of ore is indicated by the high rate of iron production per sq. ft. of hearth area of German as compared with American practice. H. A. Brassert ⁽¹¹⁾ instances German furnaces of hearth diameters not greater than 13 ft. producing more than 600 tons per day. He states: "Several causes contribute to these results, but the most important one is their more permeable burden due to an excellent coke, and a coarser ore mixture, which generally includes a considerable percentage of briquetted, agglomerated, or sintered materials. . . . Soft ores, if they contain much fines, are sintered as received without first undergoing a screening process, except that of scalping off the lumps. The hard ores are generally crushed to small sizes and the resulting fines are added to the sintering mixture. The limestone . . . is always crushed and screened. . . . They blow relatively very large amounts of wind into their small hearths, but in spite of this excessive blowing, as we would consider it, their blast pressures are always low . . . on an average 4 to 5 lb. lower than ours. . . . It is an achievement which has revealed to me new possibilities in the direction of greater productions with our present stacks, and perhaps larger tonnages with our medium-sized furnaces, than we can now produce with our largest ones, and most certainly with better practice in regard to fuel consumption, ore losses, and general uniformity of operation."

These conclusions are confirmed by the statistical analysis of the furnaces examined. Grading of the materials with elimination of fines could result in either

- (1) reduction in the iron factor with consequent low fuel consumption, or

- (2) if fuel economy were not important, the iron factor could be allowed to rise and a very high rate of production could be attained.

German results quoted by Brassert show a rate of iron production per sq. ft. of hearth area of more than 400 lb. per hour, and the attainment of this figure on comparatively small hearths suggests interesting possibilities in large hearth furnaces suitably equipped and using prepared materials of suitable quality.

Furnace Lines.

In a general way the effect of blast-furnace lines on fuel economy in blast-furnace practice was indicated by J. Gayley in 1890 when he stated that the trend of developments between 1880 and 1890 were :

- (1) 1880 : introduction of rapid driving with large outputs and high fuel consumptions.
- (2) 1885 : production of equally large amounts of iron with low fuel consumptions and slow driving.
- (3) 1890 : production of nearly double that quantity of iron with low fuel consumption through rapid driving.

In the first stage quoted by Gayley, the introduction of rapid driving was evidently accompanied by reduced time of contact ; in the second stage, with slower driving, the time of contact was increased, outputs being maintained by increasing the hearth diameter, whilst in the third stage, the effective time of contact was increased by alteration of furnace lines so as to secure more uniform distribution of gas and ore, which counterbalanced to some extent the reduced time during which the materials were in the furnace due to rapid driving.

It is not within the province of a statistical survey of blast-furnace practice to examine the nature of the lines best suited to varying conditions of blast-furnace operation to secure an optimum degree of preparation of materials entering the hearth zone, but one or two points arise out of a consideration of the data submitted in Appendix III. The first is the considerable hearth heat required to meet external cooling losses in small furnaces.

In small furnaces, driving at the rate of 150 down to 100 lb. of iron per sq. ft. of hearth area per hour, the hearth heat requirements to meet radiation, water-cooling, and other external losses as determined from the expression $500/D$, amount to 25 per cent. and upwards of the total heat production in the hearth. This figure is probably too high in some of the smaller furnaces where no bosh cooling is used, but the general consideration of the results available is sufficient to show that small furnaces with a heavy proportionate constant charge of this order on the heat production of the hearth cannot, from fundamental considerations, be as economical as large furnaces, assuming, of course, that these have sufficient blowing power and auxiliary apparatus to be used effectively.

There must be a limit to the effective hearth diameter, determined ultimately by factors governing the uniform distribution of reducing gas from the blast at a pressure and of a volume sufficient to maintain a high rate of production per unit of area in the hearth, but sufficient information is not available to determine the optimum diameter, which would possibly vary for different conditions.

In the case of some furnaces operating at high driving rates, the modern practice of using thin walls and excessive water-cooling of the bosh and hearth, although economical in so far as they assist in maintaining correct furnace lines, thus securing a more correct distribution of reducing gas and ore in the furnace, may involve a higher fuel consumption, owing to water-cooling losses, than would be given by the average value of $500/D$.

This opens up a most important field of investigation—the improvement of blast-furnace refractories. With existing refractories, water-cooling at high rates of driving is probably a necessary evil, but if an ideal refractory could be obtained which would resist the corrosive influence of slags under high-temperature conditions and satisfy the other requirements of blast-furnace operation, it might be possible to consider not only the maintenance of the most suitable lines to meet the required conditions with different ores, &c., but also the reduction of the external cooling loss.

Insulation of the shaft has already been used in certain instances, and may be of advantage in that it assists in reserving thermal energy which can be usefully employed in the reduction

process. If, further, a refractory could be obtained which would allow of the insulation of the furnace from the bosh downwards, the considerations advanced above indicate that a substantial improvement in the fuel economy of the furnace would be effected.

Factors influencing Hearth Heat.

Apart from the various factors involved in increasing the time of contact between the gas and ore, which only indirectly involve an alteration in heat requirements in the hearth, there are others, such as dry blast, which influence the fuel consumption of a furnace directly by altering the hearth heat conditions. Some of these, such as the influence of silicon, have already been discussed, and it is probable that the hearth reduction of the other metalloids, manganese and phosphorus, also plays a part, the order of which, however, would not be as important as that of silicon reduction.

In the light of the conception put forward, it is desirable to ascertain the reasons for the economy obtained with dry blast, more particularly as the theory put forward by J. E. Johnson, that the fuel requirements of a furnace are determined by the available heat in the hearth, appeared to be confirmed by the results of observations of the effect of moisture in blast. In this connection the term "hearth heat" as used by the authors differs from Johnson's conception of "available hearth heat." The authors assume that hearth heat consists of the surplus hearth heat after the standing charges required for meeting radiation and external cooling losses at critical temperatures (which are constant per unit of time whatever the throughput of the furnace) have been met. Johnson's definition of "available hearth heat," or simply "hearth heat," was that portion left over and above the amount necessary to raise the products of combustion to the critical temperature. Essentially this heat consisted of—

$$(C_1 + C_T) + C_2 + C_M - (N_T + CO_T),$$

where C_1 = heat of combustion of carbon at tuyeres ;

C_T = sensible heat of carbon at critical temperature ;

C_2 = " " in blast ;

C_M = " " of water vapour in blast ;

N_T = " " in nitrogen, leaving the hearth at critical temperature ;

and CO_T = " " in CO, leaving the hearth at critical temperature.

According to Johnson, the critical temperatures of furnaces differed, and in this fact lay an explanation of the difference in fuel consumption, say, of charcoal as compared with coke furnaces, of high-silicon and low-silicon iron manufacture, &c. The basis therefore taken by the authors differs fundamentally from that of Johnson, and the question arises whether they offer an adequate explanation of a quantitative character, not only of the results of hot blast (which they certainly do in view of the preceding analysis), but also of dry blast.

Before proceeding with a discussion of the influence of moisture in blast, it may be of service to ascertain how far the factors, as calculated by statistical methods of operating practice for carbon requirements for external heat losses, iron and slag, are in accordance with those submitted by other authorities.

It is extremely difficult to determine the actual heat losses by radiation, conduction to air and ground, and so on, in blast-furnace practice, particularly in the hearth zone. Richards⁽¹²⁾ gives a series of values for the total external heat losses in a blast-furnace, which can be averaged at approximately 800 B.th.u. per lb. of iron produced. It is difficult to estimate the proportion required in the hearth zone. Johnson⁽³⁾ (*loc. cit.*, p. 72) suggests that the heat consumption in the shaft to meet radiation and other external cooling losses amounts to 440 B.th.u. per lb. of iron, and in the hearth zone to 340 B.th.u. per lb. of iron. The data, however, from which these figures were deduced⁽¹³⁾ are by no means conclusive, but if it be assumed that 50 per cent. of the heat losses quoted by Richards take place in the hearth zone, the figures are approximately of the same order in both cases, amounting to 350 to 400 B.th.u. per lb. of iron.

An approximate comparison of this value with that deduced from the statistical average obtained by the authors can be made by taking, as an example, a furnace of 12 ft. hearth diameter, making, say, 150 lb. of iron per sq. ft. of hearth area per hour; the total amount of carbon required per sq. ft. of hearth area per hour to meet external heat losses in the hearth zone would be $500/D$ —approximately 42 lb. of carbon. Assuming that this was burnt to carbon monoxide with a production of 4375 B.th.u. per lb. of carbon, it would mean that the actual heat per lb. of iron which must be produced to meet these losses would be of the

order of 1230 B.th.u., a figure between three and four times the actual external heat losses in the hearth as calculated by Richards and Johnson.

The Slag Factor 0.28.—The actual thermal requirements of slag up to free-running temperature quoted by Clements ⁽¹⁴⁾ amounts to 1042 B.th.u. per lb. of slag. Johnson ⁽³⁾ (*loc. cit.*, p. 72) gives a somewhat lower figure of 900 B.th.u. per lb. He, however, assumes that two-thirds of the thermal requirements of the slag are obtained from the sensible heat of the gas passing up through the shaft, the actual requirements of the hearth zone being only one-third, and amounting in a thermal balance-sheet of the hearth and shaft, prepared on the assumption that 10 cwt. of slag were produced per ton of pig iron, to 300 B.th.u. per lb. of slag.

The factor 0.28 deduced by the authors amounts, on the assumption that the carbon is burnt to carbon monoxide, to approximately 1225 B.th.u. per lb. of slag, a figure again of the order of four times the theoretical heat requirements in the hearth as calculated by Johnson, but agreeing with a figure given by him *from practical experience* of 0.33 lb. of coke (say, 0.29 lb. of carbon).

The Iron Factor.—This consists of :

- (1) the equivalent carbon required to bring the reduced iron entering the hearth zone to free-running temperature, and
- (2) thermal requirements of hearth reduction, as previously explained.

The total heat of molten pig iron leaving the hearth at free-running temperature, according to Clements, is 566 B.th.u. Johnson's figure ⁽³⁾ (*loc. cit.*, p. 70) is 600 B.th.u., of which 480 B.th.u. are obtained from the shaft and 120 B.th.u. from the hearth. Summarising his calculations, the consumption of heat in the hearth for the iron is as follows :

Reduction of silicon	150 B.th.u. per lb.
Heat of iron not imparted in the shaft	120 " "
Heat for direct reduction of iron (assuming 10% direct reduction)	310 " "
Total heat requirements of the iron in the hearth	610 " "

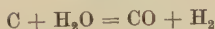
From the average equation deduced by the authors, the carbon burnt in the hearth per lb. of iron amounts to 0.56 lb.,

which, assuming the carbon to be burnt to CO, is equivalent to 2450 B.th.u. per lb. of iron, again a figure of the order of four times the theoretical requirements.

In all three cases, therefore, the actual carbon consumption in the hearth of slag and iron, or its heat equivalent to meet the requirements of radiation and external cooling losses, is of the order of three to four times the actual B.th.u. required according to the best existing authorities. This is again in accordance with customary furnace experience, that the carbon that must be burnt in order to meet thermal requirements of the system is considerably in excess of the theoretical requirements, owing to sensible heat losses in the gas from the zone considered.

Effect of Moisture in Blast.—Essentially the effect of moisture in blast is to diminish the heat available at the tuyeres, and dehydration of the blast would therefore act in the same way as an increase in blast temperature.

The heat absorbed by the reaction



amounts to approximately 2900 B.th.u. per lb. of water vapour gasified at the tuyeres.

In accordance with the convention adopted throughout this paper, and disregarding the sensible heat of the carbon burnt and, for the moment, that of the moisture in the blast, this would necessitate the combustion of $\frac{2900}{4375} = 0.66$ lb. of carbon per lb. of water vapour. At the same time, the amount of carbon necessary to meet the chemical (apart from thermal) requirements of the equation would be 0.66 lb. per lb. of water vapour, so that essentially for every 1 lb. of water vapour brought in by the blast the equivalent of 1.32 lb. of carbon would be lost for heat production at the tuyeres.

For 1 grain of moisture, the carbon requirements are $\frac{1.32}{7000}$ lb.

1 lb. of carbon burnt at the tuyeres requires 75.8 cu. ft. of air, therefore the carbon required by 1 grain of moisture in the blast

$$\text{per lb. of carbon burnt} = \frac{1.32 \times 75.8}{7000} = 0.0142 \text{ lb.}$$

From this has to be deducted the sensible heat carried in by the moisture in the blast, which, with a blast temperature of

1500° F., would amount to the equivalent of 0.002 lb. of carbon burnt at the tuyeres. Therefore, the net carbon equivalent per lb. of carbon burnt at the tuyeres of 1 grain of moisture per cu. ft. of blast at 1500° F. = $0.0142 - 0.002 = 0.0122$ lb.

Through the courtesy of Mr. E. H. Lewis, the authors are able to reproduce in Table II. particulars of the operation of a small coal-fired blast-furnace for the first seven months of 1925 and from July to October 1927. These results have been analysed in Table III. in order of increasing moisture content in the blast, and in accordance with the statistical methods outlined in the preceding notes. In the final corrected iron factor, allowance

TABLE II.—*Operating Results, with Normal and Dry Blast, of a Small Furnace using Coal as Principal Fuel.*

Date.	Output.		Total Carbon consumed. Lb. per Ton of Iron.	Silicon in Pig Iron. %	Slag per Ton of Pig Iron. Owt.	Moisture in Blast. Grains per cu. ft.
	Tons	Owt.				
1925.						
January . . .	1919	18	2005	2.64	7.30	2.6 (?)
February . . .	1723	15	1930	2.46	7.35	2.6 (?)
March . . .	1902	4	1848	2.73	6.93	2.5 (?)
April . . .	1869	11	1951	2.72	7.27	3.0 (?)
May . . .	1960	4	1968	2.60	7.02	3.7 (?)
June . . .	1906	11	1878	2.09	8.82	4.2 (?)
July . . .	2118	3	2008	2.08	7.37	4.8 (?)
1927.						
July . . .	2127	2	1880	2.62	7.49	1.61
August . . .	2127	19	1883	2.69	7.79	1.50
September . . .	2017	14	1873	2.59	7.71	1.36
October . . .	2016	15	1911	2.54	7.85	1.45

has been made for all the factors which, up to the present, have been found to affect the results—namely, (1) blast temperature, (2) silicon in pig iron, (3) variation in rate of driving, (4) variation in heat requirements owing to difference in slag weights, and (5) thermal requirements of moisture in blast. It will be seen that the hearth heat requirements increase apparently with increasing moisture content of the blast at a much greater rate than would be accounted for by the thermal effect at the tuyeres after making due allowance for all known factors.

TABLE III.—Analysis of Operating Results with Normal and Dry Blast, given in Table II.

	1927. Dry Blast.				1925. Wet Blast.						
	Sept.	Oct.	Aug.	July.	March.	Jan.	Feb.	April.	May.	June.	July.
Moisture. Grains per cu. ft. . . .	1.36	1.45	1.50	1.60	2.5	2.6	2.6	3.0	3.7	4.2	4.8
Thermal requirements for moisture per lb. of carbon burnt, expressed as "equivalent carbon," Lb. .	0.01665	0.01775	0.01840	0.01970	0.0306	0.0318	0.0318	0.0367	0.0453	0.0515	0.0588
Carbon burnt at tuyeres per sq. ft. of hearth area per hr. Lb. . . .	67.10	65.12	68.94	68.78	60.2	67.2	63.7	65.4	67.0	67.8	74.2
Heat requirements of moisture in blast. Lb. of carbon per sq. ft. of hearth area per hr. . . .	1.12	1.16	1.27	1.355	1.843	2.14	2.02	2.40	3.04	3.49	4.36
"Equivalent carbon" (including sensible heat in blast). Lb. per sq. ft. of hearth area per hr. . . .	99.04	96.12	101.76	101.52	88.9	99.2	94.0	96.4	99.0	100.0	109.5
"Equivalent carbon," corrected for moisture. Lb. per sq. ft. of hearth area per hr. . . .	97.92	94.96	100.49	100.16	87.06	97.06	91.98	94.00	95.96	96.51	105.14
Thermal requirements for slag and external heat losses. Lb. of carbon per sq. ft. of hearth area per hr. .	66.21	66.05	66.54	66.11	64.3	64.9	64.9	64.9	64.8	67.1	66.0
Surplus available heat. Lb. of carbon per sq. ft. of hearth area per hr. .	31.71	28.91	33.95	34.05	22.76	32.16	27.08	29.10	31.16	29.41	39.14
Iron produced. Lb. per sq. ft. of hearth area per hr. . . .	98.70	95.47	100.73	100.69	90.0	90.9	90.4	91.4	92.8	93.2	100.2
"Iron factor,"	0.321	0.303	0.337	0.338	0.253	0.353	0.299	0.318	0.336	0.316	0.362
Correction for 2% silicon	0.071	0.065	0.083	0.074	0.088	0.077	0.065	0.086	0.072	0.011	0.010
"Iron factor," corrected to 2% silicon .	0.250	0.238	0.254	0.264	0.165	0.276	0.234	0.232	0.264	0.305	0.382
Correction to 100 lb. of iron per sq. ft. of hearth area per hr. . . .	0.006	0.023	— 0.004	— 0.004	0.050	0.045	0.047	0.043	0.036	0.034	Nil
"Iron factor," corrected to 100 lb. of iron per sq. ft. of hearth area per hr. .	0.256	0.261	0.250	0.260	0.215	0.321	0.291	0.275	0.300	0.339	0.382

This has been noted previously by other investigators who have attempted to account quantitatively for the effect of drying the blast. The results are plotted in Fig. 8, and this diagram appears to indicate that the increase for hearth heat requirements, at least for the range above 1 grain per cu. ft., appears to be a lineal function of the moisture content. (This was pointed out by Mr. E. H. Lewis in a private communication, as a result of earlier calculations in which no allowance was made for either the purely thermal effect of the moisture or for variations in time of contact of ore and gases.) Much more information is desirable before any definite quantitative expression can be put forward, but it is interesting to note that Professor W. A. Bone, in dealing with this question as far back as 1918, suggested the advisability of considering the possibility, among the contributory causes of fuel economy affected by dry blast, apart from purely thermal ones, that "any considerable elimination of moisture from the blast would be very likely to accelerate the reducing action of the furnace gases upon the oxides of iron in the middle and upper region of the furnace." ⁽¹⁵⁾

In this connection, Professor W. A. Bone, L. Reeve, and H. L. Saunders ⁽¹⁶⁾ have recently shown that the addition of 2 per cent. of hydrogen to the blast-furnace gas mixture used in their investigations of blast-furnace reactions had a marked influence on the phenomena of the reduction of the ores tested at a temperature of 550° C. Higher temperatures have yet to be explored, but it is conceivable that the presence of hydrogen in blast-furnace gas may have an important effect on the degree of preparation of the materials in the shaft, and thus ultimately affect the hearth heat requirements.

It may be that these effects are to some extent masked under conditions where 90 per cent. of the fuel used consists of coal, which gives a gas containing a high proportion of hydrogen, but the preliminary results indicated in Fig. 8 are sufficiently outstanding to indicate the necessity of further investigation of the phenomenon discovered by these workers. (A further interesting speculation arises from a consideration of Fig. 8. Points *A*, *B*, and *C* on the curve refer to consecutive months, their average value being plotted at *D*; taking this value *D* into consideration with the remaining points on the curve, there appears to be

a diminishing rate of decrease of hearth heat reduction with diminishing moisture content. It is well known that chemical

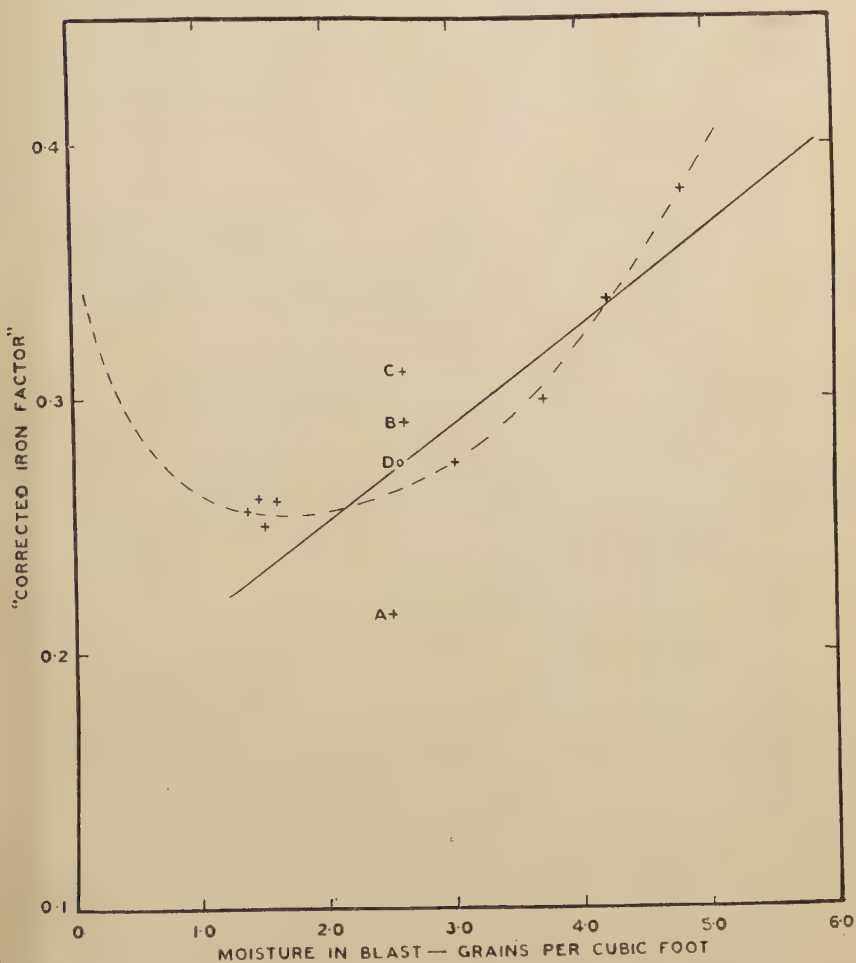


FIG. 8.—Relationship between the Moisture in the Blast and the "Corrected Iron Factor."

reactions proceed with extreme slowness under conditions of *absolute* dryness, so that with absolutely dry blast the hearth heat requirements would be of an *extremely large* order. One

would therefore anticipate a tendency towards increasing hearth heat requirements, once the moisture content of the blast had dropped below a certain, at present undefined, limit ; the resulting thermal effect is shown by the hypothetical (dotted) curve. Whether this would be substantiated in practice remains to be seen, but further information on this point would be of the greatest scientific as well as practical interest.)

Unknown Factors.—There are one or two factors which do not allow of analysis, namely :

- (1) The personal factor involved in methods of control and operation of the furnace.
- (2) The factor called, by Continental blast-furnace managers, the “temperament” of the furnace.

These factors would affect both the rates of driving and the iron factor (X), and a proportion of this factor X would always remain to some extent “unknown.” Records of operating practice submitted by blast-furnace managers, however, are generally those of furnaces working at their best, so that in the preceding examination there has been, to some extent, an elimination of the effects due to personal or other causes which might reduce the efficiency of the furnace operation.

The mathematical expression ultimately developed agrees qualitatively with customary blast-furnace experience, and offers the advantage that it links up the functions of the hearth and shaft in one general equation. For the moment, however, these notes must be regarded as a progress report, and must not be considered to do more than represent an actuarial average of furnaces examined, which, as results accumulate, is definitely open to modification and development.

The authors desire to acknowledge the help and advice received throughout the investigation from members of the Fuel Economy Committee of the National Federation of Iron and Steel Manufacturers, and particularly from the Chairman of the Committee, Mr. M. Mannaberg, at whose instance the work was initiated.

They desire also to acknowledge the invaluable assistance they have received from blast-furnace managers in all parts of the

world, and also from technical and research societies and the leading authorities in Belgium, France, Germany, Luxemburg, the United States of America, India, and the British Dominions overseas, by whom data with regard to operating practice, many of which have not hitherto been published, have been placed freely at the disposal of the authors.

APPENDIX I.

Carbon Gasified at the Tuyeres.

An estimate of the carbon gasified at the tuyeres may be obtained by using Howland's formula ⁽¹⁷⁾:

$$C_1 = \frac{\text{total carbon gasified} \times \% N_2 \times 40.06}{(\% CO + \% CO_2) \times 75.8}$$

Where C_1 = carbon gasified at the tuyeres.

Total carbon gasified = fixed carbon in coke + carbon in limestone and ore - carbon in pig - carbon in flue-dust.

Although these figures may be estimated fairly closely if particular care be taken to obtain fair averages, in the normal run of operating returns the figures making up the total carbon gasified are either not returned at all, or the accuracy is open to doubt. An even more serious source of error, however, lies in the figures reported for the average gas analyses. In the first place, it is extremely difficult, without continuous sampling and analysis, to obtain figures which are representative averages. Secondly, the carbon monoxide and carbon dioxide percentages which are determined by absorption methods are seldom of a high degree of accuracy in the ordinary run of routine works analyses. Moreover, since the absorption is very liable to be incomplete, the tendency is to return figures which are too low in both cases. This, of course, means that the calculated figure for the carbon gasified at the tuyeres tends to be too high.

The carbon utilised other than at the tuyeres has been the subject of much discussion, and an attempt at analysis was made by W. D. Brown.⁽¹⁸⁾ Although Brown's methods appear to be satisfactory in the cases he quotes, it was found to be impossible to reconcile the methods with the full range of returns available. Eventually the carbon used other than at the tuyeres per ton of iron made was calculated for a large number of the returns,

using Howland's formula. A frequency diagram, Fig. 9, was constructed ; this shows that there is a well-defined peak a little below 350 lb. per ton, and also that the number of returns giving figures below this value is greater than those above. In fact, the general shape of the curve agrees closely with what would be

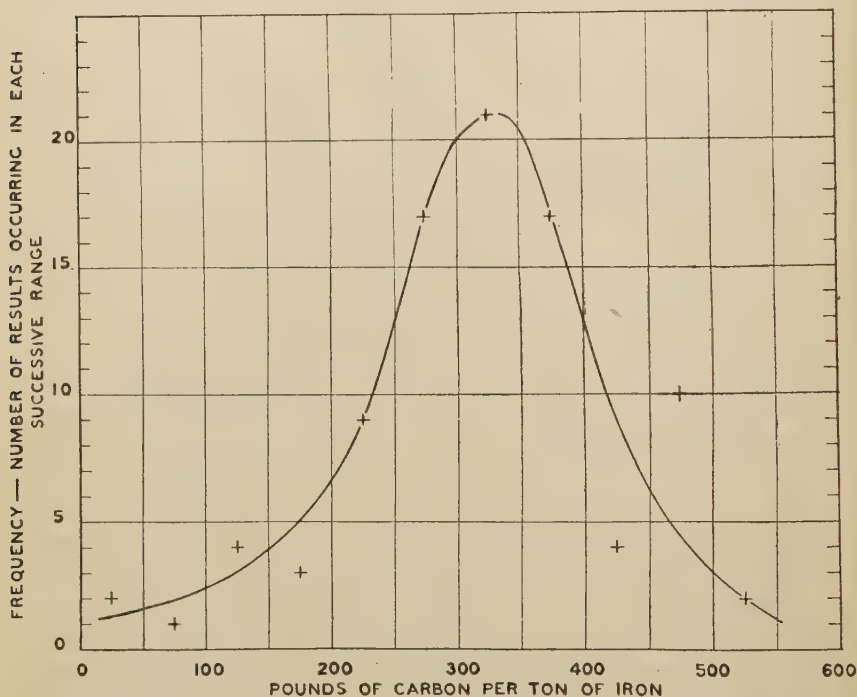


Fig. 9.—Frequency-Distribution Diagram showing lb. of Carbon used other than at the Tuyeres per ton of Iron made. Calculated from 91 furnaces.

expected from a series of results dependent on a final equilibrium of effects of variable factors on which is superimposed a constant tendency in one direction. The normal errors in gas analysis previously mentioned would be sufficient to account for the latter tendency, and, in fact, for the greater proportion of the variation in the calculated figures.

It seems at first sight difficult to justify a figure for carbon used other than at the tuyeres which is approximately a constant per ton of iron made. This figure, however, is controlled by two

conflicting reactions—namely, the carbon gasified by solution by carbon dioxide (whether formed by hearth reduction or by other means) and the carbon deposited in the ore, and these in turn are controlled by the dynamic equilibria attained under blast-furnace conditions. Moreover, the solution of carbon takes place first (lower down the furnace), and is afterwards to some extent balanced by the carbon deposition in the ore. Thus the final equilibrium of the carbon used other than at the tuyeres is controlled by a reaction with the iron oxide of the ore. So far there has been insufficient investigation into the velocities at which the respective equilibria are attained, so that it is considered justifiable for the purposes of this work to assume a constant figure of 350 lb. per ton (*cf.* Joseph ⁽¹⁹⁾). In the case of a group of certain British furnaces, however, the figures calculated undoubtedly gave an average somewhat above this value, although no cause could be assigned to it. This group accounts for the higher frequency to be noticed in the 450–500-lb. band.

APPENDIX II.

Estimation of Time required for Stock to reach the Tuyere Zone.

In view of the importance of the effect of time of contact in the furnace, a number of practical operators were asked to submit estimates for the furnaces under consideration. It was found, however, that since the method of estimation was not standardised, the figures submitted were not comparable. An investigation of the problem showed that, although insufficient data are available for the attainment of absolute accuracy, it is possible to obtain a reasonable comparative accuracy by calculation. The method of calculation is shown in the following example, No. 17, and some results are summarised in Table IV. (p. 92).

(1) *The Volume of the Furnace.*—The useful volume of a blast-furnace is the sum of the volumes of two truncated cones placed base to base. The volume of the frustum of a cone is—

$$V = 0.2618 \times H \times (D^2 + Dd + d^2).$$

Where V = volume in cu. ft. ;

H = height in ft. ;

D = major diameter in ft. ;

d = minor diameter in ft.

TABLE IV.—Time of Stock Descent.

Furnace No.	Useful Furnace Volume, Cu. ft.	Coke, Lb. per ton.	Ore, Lb. per ton.	Limestone, Lb. per ton.	Coke Volume per Ton, Cu. ft.	Ore Volume per Ton, Cu. ft.	Limestone Volume per Ton, Cu. ft.	Burden Volume Cu. ft.	Iron made per Tons.	Volume required per Cu. ft.	Time in Furnace, Hours.
2	5,700	2445	4370	868	77.6	35.3	9.4	122.3	5.18	634	9.0
3	11,700	2575	4340	902	85.0	38.8	9.8	133.6	7.69	1027	11.4
4	10,400	2268	4430	753	72.0	34.0	8.2	114.2	7.08	1809	12.9
5	13,200	2248	4870	840	71.4	48.7	9.1	129.2	10.56	1365	9.7
6	16,500	2185	4260	672	69.4	42.6	7.3	119.3	11.01	1314	12.6
8	18,200	2688	6050	1064	85.3	60.5	11.5	157.3	6.53	1026	17.7
9	9,700	2771	4340	771	86.3	33.4	8.4	128.1	8.74	1120	8.7
10	23,100	1736	7900	1736	87.6	79.0	18.9	185.5	5.30	893	23.5
11	10,900	2540	3990	843	80.6	33.4	9.2	123.2	5.54	683	16.0
12	9,400	2665	5600	784	84.6	50.0	8.5	143.1	8.93	1278	7.4
16	16,300	3530	8960	1590	112.0	91.4	...	203.4	6.25	1271	12.8
17	10,900	3530	5580	1590	112.0	49.8	17.3	179.1	5.56	960	11.4
18	9,900	3165	7120	...	100.5	72.7	...	173.2	4.76	824	12.0
19	11,100	3142	7070	...	99.8	72.2	...	172.0	5.65	972	11.4
20	13,900	3560	7320	124	106.6	65.4	...	185.1	5.36	992	14.4
21	18,200	3248	8080	...	103.1	82.0	...	157.1	4.17	655	18.3
22	9,200	2807	6400	...	89.1	65.3	...	157.1	5.59	968	14.0
23	8,400	2912	4980	1120	92.5	44.5	2.7	159.5	4.02	641	13.1
24	9,900	3530	7030	1344	112.0	63.9	12.5	190.7	4.61	879	11.3
25	11,000	3125	6100	1120	99.3	55.4	12.5	167.2	5.80	970	11.3
26	11,900	3388	6960	...	107.5	71.0	...	178.5	2.38	425	28.0
27	13,100	2577	5040	1456	81.8	43.8	16.3	141.9	7.74	1098	11.9
28	19,000	2577	6550	...	81.8	65.5	...	147.3	8.33	1226	15.5
29	18,600	2360	4220	419	75.0	38.4	4.7	118.1	8.93	1055	17.6
32	15,700	2104	4410	736	66.8	36.7	8.2	111.7	12.50	1396	11.2
33	16,000	2352	3920	560	74.7	27.0	6.2	107.9	10.11	1090	13.8
34	13,800	2374	4290	627	75.4	39.0	7.0	121.4	8.33	1011	13.6
35	18,150	2142	4200	905	68.0	35.0	10.1	113.1	17.26	1952	9.3
36	10,600	2857	5870	...	90.7	58.7	...	149.4	6.25	984	11.4
37	17,200	1800	4160	837	57.2	34.7	9.3	151.2	4.53	488	37.6
39	7,500	2960	6420	...	94.0	58.4	...	152.4	3.42	521	14.4
40	12,900	2912	5750	1904	100.3	50.0	20.7	163.2	5.35	874	14.8
41	12,900	3160	5230	1477	92.5	45.5	16.0	161.8	5.35	866	14.9
42	11,200	2815	5980	869	89.4	59.8	9.5	158.7	5.83	926	12.1
43	11,200	4095	5840	907	130.0	58.4	9.9	198.3	5.29	1049	10.7
44	11,200	3555	6160	771	112.9	61.6	8.4	182.9	5.93	1085	10.3
45	7,700	3370	5040	1610	107.0	45.8	17.5	170.3	3.51	598	12.9
46	8,000	3100	6160	1304	98.5	56.0	20.7	175.2	3.87	678	11.8
47	2070	2070	4200	784	65.7	36.0	8.5	109.2	19.65	2148	7.2
49	7,650	2464	5820	672	78.3	52.9	7.3	138.5	6.55	907	8.4
50	7,000	2112	3770	800	79.2	30.2	9.0	118.1	2.74	324	21.6
51	7,000	2110	3770	825	80.3	30.2	9.0	119.5	2.85	340	20.6

Table V. gives the values of the function ($D^2 + Dd + d^2$) for the values of D and d met with in blast-furnace practice.

The bosh height	= 10 ft.
$0.2618 \times$ the bosh height	= 2.62 ft.
The hearth diameter	= 12.5 ft.
The bosh diameter	= 20 ft.
$(D^2 + Dd + d^2)$ from Table V.	= 806 sq. ft.
The bosh volume	= $2.62 \times 806 = 2110$ cu. ft.
The shaft height (to stockline)	= 40.5 ft.
$0.2618 \times$ the shaft height	= 10.60 ft.
The stockline diameter	= 13 ft.
The bosh diameter	= 20 ft.
$(D^2 + Dd + d^2)$ from Table V.	= 829 sq. ft.
The shaft volume	= $10.60 \times 829 = 8790$ cu. ft.

Useful furnace volume = $2110 + 8790 = 10,900$ cu. ft.

TABLE V.—Values of Function ($D^2 + Dd + d^2$) in the Equation for the Volume of the Frustum of a Cone, for Dimensions of D and d met with in the Blast-Furnace.

$$V = 0.2618H (D^2 + Dd + d^2),$$

where V = volume, H = height, and D and d = larger and smaller diameters respectively.

d	15.	16.	17.	18.	19.	20.	21.	22.	23.	24.	25.	26.
5	325	361	399	439	481	525	571					
6	351	388	427	468	511	556	603	652				
7	379	417	457	499	543	589	637	687	739			
8	409	448	489	532	577	624	673	724	777	832		
9	441	481	523	569	613	661	711	763	817	873	931	
10	475	516	559	604	651	700	751	804	859	916	975	1036
11	511	553	597	643	691	741	793	847	903	961	1021	1083
12	549	592	637	684	733	784	827	892	949	1008	1069	1132
13	589	633	679	727	777	829	883	939	997	1057	1119	1183
14	631	676	723	772	823	876	931	988	1047	1108	1171	1236
15	675	721	769	819	871	925	981	1039	1099	1161	1225	1291
16		768	817	868	921	976	1033	1092	1153	1216	1281	1348
17			867	919	973	1029	1087	1147	1209	1273	1339	1407
18				972	1037	1084	1143	1204	1267	1332	1399	1468
19					1083	1141	1201	1263	1327	1393	1461	1531
20						1200	1261	1324	1387	1456	1525	1596
21							1323	1387	1453	1521	1591	1663
22								1452	1519	1588	1659	1732
23									1587	1657	1729	1803
24										1728	1801	1876

The volumes occupied by the various materials charged are calculated on the basis of the averages of apparent weights

per cu. ft. kindly supplied by a number of blast-furnace managers :

	Lb. per Cu. Ft.
Coke	31·5
Limestone	92·0
Ores :	
Lincolnshire	98·0
Cleveland	100·0
Northants	112·0
Rubio, &c.	116·0
Calcined spathic, &c.	124·0
Cumberland	145·0
Scandinavian	170·0

The quantities charged per ton of pig iron made were coke 3530, ore 5580, and stone 1590 lb. ; the volumes occupied as charged were accordingly coke 112·0, ore 49·8, and stone 17·3 cu. ft. per ton, giving a volume of burden of 179·1 cu. ft. per ton of pig, assuming no packing of the stock.

The furnace was at this time making 5·36 tons of iron per hour, so that the volume of burden passing per hour was $179·1 \times 5·36 = 960$ cu. ft. per hour, and the time taken to reach the tuyeres was $\frac{10,900}{960} = 11·4$ hours.

APPENDIX III.

Operating Data concerning Blast-Furnace Practice.

The tabular statement on the following pages contains details of construction and operation of a large number of blast-furnaces in all parts of the world. A large part of the information has been communicated privately to the National Federation of Iron and Steel Manufacturers by authorities in Great Britain, Germany, Belgium, Czecho-Slovakia, Luxemburg, Lorraine, and India ; the remainder is quoted from the following sources :

British :

- F. CLEMENTS : *Journal of the Iron and Steel Institute*, 1920, No. I. pp. 125-148.
 F. CLEMENTS : *Proceedings, Empire Mining and Metallurgical Congress*, 1924, Part 4, pp. 45-63.

German :

- Anhaltzahlen für den Energieverbrauch in Eisenhüttenwerken.* Wärmestelle, Düsseldorf. (Verein deutscher Eisenhüttenleute.)

American :

- P. H. ROYSTER, T. L. JOSEPH, and S. P. KINNEY : *Blast-Furnace and Steel Plant*, 1924, vol. xii. pp. 200-204.
- G. ST. J. PERROTT and S. P. KINNEY : *Transactions of the American Institute of Mining and Metallurgical Engineers*, 1923, vol. lxix. pp. 543-584.
- J. GAYLEY : *Journal of the Iron and Steel Institute*, 1904, No. II. pp. 274-300.
- J. P. DOVEL : *Iron Age*, 1927, vol. cxx. pp. 782-784.

Luxemburg, Lorraine, and Saar :

- A. WAGENER : *Revue Technique Luxembourgeoise, Special Number*, 1927, June, pp. 15-27 ; *Fuel Economist*, 1928, vol. iii. pp. 301-302, 381-385.

APPENDIX III.—Operating Data

A	Furnace No.		1.	2.	3.
B	Furnace lines	Height	89' 6"	55' 6"	86' 0"
		Hearth diameter	14' 0"	10' 0"	12' 0"
		Bosh diameter	19' 6"	16' 0"	18' 8"
		Bosh height	13' 0"	16' 6"	14' 6"
C	Pig iron	Output per week. Tons	1486	870	1292
		Character	Basic	Hematite	Foundry
		Analysis. %	Si 1.00	2.71	2.35
			S 0.08	0.03	0.07
			P 1.60	0.05	1.20
			Mn 1.00	0.99	0.75
			C ...	...	...
D	Coke	Consumption per ton pig. Lb. .	2688	2445	2675
		Character	Good	Good	Good
		Average analysis. %	Fixed carbon 84.96	84.78	87.20
			Ash 10.32	10.09	9.21
			Moisture 3.49	1.07	3.00
			Sulphur 1.32	0.62	0.90
E	Limestone	Consumption per ton pig. Lb. .	1386	868	902
F	Ore	Consumption per ton pig. Cwt.	43.8	39.0	43.2
G	Blast	Temperature. ° F.	1075	1320	1290
		Pressure. Lb. per sq. in. . . .	9½-10	5 (at engines)	6½
H	Slag	Production per ton pig. Lb. .	2067	971	1680
		Analysis. %	SiO ₂ 30.50	30.00	31.13
			CaO 45.00	41.94	43.95
			Al ₂ O ₃ 16.50	16.73	18.53
			MgO 4.50	5.44	3.83
			S 2.10	2.15	1.79
			FeO 0.60	0.77	1.00
			MnO 0.80	0.48	0.51
J	Gas	Analysis. %	CO ₂ 10.5	11.0	8.29
			CO 29.5	28.7	30.61
			H ₂ 2.5	3.0	3.29
		Temperature. ° F.	N ₂ 57.5	57.3	57.81
K	Iron produced.	Lb. per sq. ft. of hearth area per hr.	...	...	...
			128.7	147.6	152.3
L	Slag produced.	Lb. per sq. ft. of hearth area per hr.	118.7	64.0	114.2
M	Carbon gasified at tuyeres.	Lb. per sq. ft. of hearth area per hr.	111.0	113.5	134.9
N	Equivalent carbon (including sensible heat in blast).	Lb. per sq. ft. of hearth area per hr.	148.8	161.0	190.0
O	External loss requirements—as lb. of equivalent carbon per sq. ft. of hearth area per hr.		35.7	50.0	41.7
P	Slag requirements—as lb. of equivalent carbon per sq. ft. of hearth area per hr.		33.2	17.9	32.0
Q	Iron factor (including silicon)		0.621	0.630	0.764
R	Iron factor (excluding silicon)		0.501	0.305	0.482

concerning Blast-Furnace Practice.

4.	5.	6.	7.	8.	9.	10.	11.	12.	A
82' 0"	81' 0"	79' 0"	84' 0"	80' 0"	74' 0"	85' 0"	76' 0"	72' 9"	B
10' 6"	13' 0"	13' 0"	8' 6"	13' 0"	12' 6"	10' 0"	11' 0"	11' 0"	
19' 0"	21' 0"	21' 6"	...	22' 10"	18' 8"	25' 6"	20' 0"	19' 10"	
12' 6"	11' 6"	14' 6"	...	16' 6"	14' 6"	27' 9"	17' 9"	15' 6"	
1190	1775	1850	941	1097	1468	890	930	1450	C
Hematite	Basic O.H.	...	Hema- tite	Foundry	Hema- tite	Foundry	Hema- tite	Basic	
2.29	1.68	1.79	2.75	2.80	2.13	2.12	...	0.70-1.25	
0.036	0.084	0.058	0.04	0.04	0.036	0.063	...	0.08-0.04	
0.046	0.98	...	0.04	1.00	0.056	1.59	...	1.25-1.50	
1.73	0.73	1.16	1.40	0.75	1.19	0.55	...	1.75-2.25	
3.86	...	3.99	3.90	3.70	...	3.39	...	...
2268	2248	2185	2311	2688	2718	2758	2540	2520	D
Good	Good	Good	Good	Good	Good	(Good + 10% medium)	Good	Moderate	
83.49	81.03	83.38	85.99	85.00	82.72	84.66	85.00	79.0	
10.78	8.89	10.19	9.48	9.00	11.27	12.93	12.00	10.7	
4.00	7.48	4.40	3.24	3.00	3.82	1.71	1.80	8.0	
1.05	1.15	1.04	1.29	0.95	1.08	1.00	1.20	1.45	
753	840	672	755	1064	771	1736	843	730	E
39.6	43.5	38.0	34.7	54.0	38.77	70.56	35.60	45.5	F
Scrap 1.1				Scrap 1.5					
1200	1350	1400	1000	1300	1250	1195	1200	1100	G
6 to 7 (at tuyeres)	9	9½	6¼	6	8	6½ (cold blast)	7	9½	
1232	1905	1343	896	2352	1190	3900	842	2350	H
29.75	30.16	31.26	29.65	30.50	27.24	31.46	25.10	31.0	
41.60	38.92	41.30	38.18	36.50	39.53	33.61	51.20	42.0	
16.50	19.58	14.70	13.89	...	16.25	24.96	14.70	16.0	
5.00	7.29	4.05	14.79	6.90	7.46	7.30	5.40	2.0	
2.00	...	2.47	2.92	1.85	3.19	...	3.59	2.5	
...	0.70	1.67	...	...	0.96	0.24	...	1.5	
2.00	0.75	1.23	0.57	...	1.03	0.93	...	...
11.9	7.30	9.8	...	9.4	7.0	7.5	8.5	10.0	J
25.7	29.50	29.1	...	30.1	31.1	30.5	29.8	28.0	
2.6	1.80	1.4	...	2.5	2.8	1.0	1.9	3.0	
59.8	61.40	59.7	...	58.0	59.1	61.0	59.0	59.0	
...	...	...	...	...	...	...	...	400	
183.1	178.2	185.8	221.0	110.1	159.2	151.0	130.4	203.5	K
100.7	151.6	111.4	88.5	115.8	84.6	260.0	49.0	213.5	L
126.3	117.2	122.1	161.6	95.2	135.1	132.0	104.4	149.0	M
174.3	167.4	178.3	212.9	134.5	188.7	183.4	144.0	201.0	N
47.6	38.5	38.5	58.8	38.5	40.0	50.0	45.5	45.4	O
28.2	42.5	31.2	24.8	32.4	23.7	72.8	13.7	59.8	P
0.535	0.485	0.584	0.585	0.577	0.785	0.401	...	0.471	Q
0.260	0.283	0.369	0.256	0.241	0.529	0.147	...	0.350	R

A		Furnace No.		13.	14.	15.
B	Furnace lines	Height		75' 6"	80' 0"	75' 0"
		Hearth diameter		12' 0"	12' 6"	11' 0"
		Bosh diameter		21' 0"	20' 3"	21' 0"
		Bosh height		22' 6"	13' 6"	16' 0"
C	Pig iron	Output per week. Tons		2034	1674	1175
		Character		Hema- tite	Hema- tite	Hema- tite
			Si	1.73	2.50	2.0-4.0
			S	0.018	0.016	...
			P	0.024	0.025	...
			Mn	0.32	0.90	...
D	Coke	Consumption per ton pig. Lb.		2038	2550	2604
		Character		Good	Good	Moderate
			Fixed carbon	89.31	88.00	82.5
			Ash	6.93	8.75	9.0
			Moisture	2.42	2.13	6.0
E	Limestone	Consumption per ton pig. Lb.		829	1485	1182
F	Ore	Consumption per ton pig. Cwt.		33.09	35.71	37.50
G	Blast	Temperature. ° F.		1250	1200	1300
		Pressure. Lb. per sq. in. . . . .		...	...	7½ (at blower)
H	Slag	Production per ton pig. Lb.		926	1344	1485
			SiO ₂	...	31.50	...
			CaO	...	54.00	...
			Al ₂ O ₃	...	8.85	...
			MgO	...	3.10	...
			S	...	2.30	...
			FeO	...	...	...
			MnO	...	...	...
J	Gas		CO ₂	13.34	9.75	8.68
			CO	27.32	29.80	29.70
			H ₂	1.54	2.00	1.42
			N ₂	57.60	58.45	60.00
		Temperature. ° F.		440	...	...
K	Iron produced.	Lb. per sq. ft. of hearth area per hr.		240.0	181.8	164.7
L	Slag produced.	Lb. per sq. ft. of hearth area per hr.		99.2	109.1	109.2
M	Carbon gasified at tuyeres.	Lb. per sq. ft. of hearth area per hr.		157.5	153.7	132.4
N	Equivalent carbon (including sensible heat in blast).	Lb. per sq. ft. of hearth area per hr.		220.0	212.1	187.0
O	External loss requirements—as lb. of equivalent carbon per sq. ft. of hearth area per hr.			41.7	40.0	45.5
P	Slag requirements—as lb. of equivalent carbon per sq. ft. of hearth area per hr.			27.8	30.5	30.5
Q	Iron factor (including silicon)			0.627	0.779	0.674
R	Iron factor (excluding silicon)			0.419	0.479	...

(continued).

16.	17.	18.	19.	20.	21.	22.	23.	24.	A
80' 0"	70' 0"	71' 0"	71' 0"	80' 0"	85' 0"	65' 0"	68' 0"	71' 0"	B
11' 6"	12' 6"	11' 0"	11' 0"	11' 0"	12' 0"	10' 0"	8' 6"	11' 0"	
21' 0"	20' 0"	18' 6"	20' 0"	19' 10"	23' 0"	16' 6"	16' 0"	18' 6"	
13' 4"	10' 0"	13' 6"	13' 6"	15' 9"	15' 8"	17' 6"	11' 6"	13' 6"	
1050	900	800	950	940	900	700	675	775	C
Basic	Foundry	Basic	Basic	Basic	Basic	Basic	Basic	Foundry	
0.80	3.57	1.2	1.25	1.21	0.75	2.03	0.90	3.10	
0.07	0.005	0.058	0.06	0.036	0.065	0.097	0.08	0.026	
1.69	1.55	1.69	1.75	1.80	1.2	2.31	2.1	1.43	
1.60	0.30	1.65	1.56	1.86	1.5	1.38	1.9	0.81	
...	3.28	3.00	3.00	...	...	2.50*	3.5	3.55	
3530	3530	3165	3142	3360	3248	2807	2912	3530	D
Weak	Soft and small	Mod.	Mod.	Mod.	Mod.	Mod. small and soft	Mech. weak	Fairly soft	
79.0	83.7	82.0	82.0	78.5	81.0	84.5	76.0	79.0	
11.8	10.1	10.0	10.0	13.5	11.0	11.0	15.0	12.5	
8.5	4.8	7.0	7.0	7.5	7.5	4.0	5.0	8.0	
...	
...	1590	...	...	124	...	239	1120	1344	E
80	49.80	63.49	63.14	65.3	71.7	57.1	44.5	62.8	F
850	1200	1100	1020	700	850	1325	1200	1200	G
10	6½ to 10	5 to 6	6 to 6½	7	9	6	6	6	
3360	2520	2520	2520	3180	2800	2550	2800	3025	H
32.0	32.35	34.1	32.8	30.0	31.0	32.0	31.0	27.9	
44.0	41.50	43.1	43.8	43.0	43.0	43.0	42.0	46.6	
16.5	19.55	14.8	14.8	19.0	18.5	18.4	16.0	18.5	
3.5	3.55	1.2	1.6	3.0	...	4.1	...	2.5	
...	
1.5	0.64	1.9	1.9	2.5	...	...	...	1.2	
2.0	...	1.75	1.6	1.0	...	1.6	3.0	0.4	
7.0	7.46	8.25	8.65	6.0	7.0	5.0	8.0	10.4	J
30.8	30.00	28.50	28.65	30.0	30.0	29.0	31.0	26.9	
4.1	1.48	2.00	3.0	4.6	2.5	2.2	2.1	3.1	
58.1	61.06	61.25	59.7	58.4	60.5	63.8	58.9	59.7	
392	350	400	350	300	300	325	500	300	
134.7	97.8	112.1	133.1	131.6	106.1	118.7	158.7	108.5	K
202.0	110.0	126.1	149.9	187.0	132.6	135.1	198.4	146.5	L
146.5	113.6	112.4	132.3	134.5	108.0	107.1	131.9	118.0	M
186.1	156.9	151.5	175.1	164.4	137.1	152.1	182.1	162.9	N
43.5	40.0	45.5	45.5	45.5	41.7	50.0	58.8	45.5	O
56.6	30.8	35.3	42.0	52.4	37.1	37.8	55.6	41.0	P
0.638	0.881	0.631	0.658	0.505	0.549	0.542	0.427	0.704	Q
0.542	0.431	0.487	0.508	0.350	0.459	0.298	0.319	0.332	R

A	Furnace No.				25.	26.	27.
B	Furnace lines	Height . . . . .	. . . . .	. . . . .	71' 0"	70' 0"	76' 0"
		Hearth diameter . . . . .	. . . . .	. . . . .	11' 0"	10' 0"	12' 6"
		Bosh diameter . . . . .	. . . . .	. . . . .	20' 0"	18' 6"	20' 0"
		Bosh height . . . . .	. . . . .	. . . . .	13' 6"	13' 0"	10' 9"
C	Pig iron	Output per week.	Tons . . . . .	. . . . .	975	400	1300
		Character . . . . .	. . . . .	. . . . .	Basic	Basic	Basic
	Analysis. %	{	Si	0.78	0.60	1.00	
			S	0.068	0.08	0.10	
			P	1.22	1.05	1.25	
			Mn	0.177	1.40	1.00	
	C	...	3.40	3.40			
D	Coke	Consumption per ton pig.	Lb. . . . .	. . . . .	3125	3388	2577
		Character . . . . .	. . . . .	. . . . .	Fairly soft	Variable. Soft and dirty	Good
		Average analysis. %	{	Fixed carbon	81.0	80.0	80.0
				Ash	11.0	12.0	12.0
				Moisture	7.0	7.5	7.5
				Sulphur	...	...	...
E	Limestone	Consumption per ton pig.	Lb. . . . .	. . . . .	1120	...	1456
F	Ore	Consumption per ton pig.	Cwt. . . . .	. . . . .	54.5	62.1	45.0
G	Blast	Temperature. ° F. . . . .	. . . . .	. . . . .	1000	900	1000
		Pressure. Lb. per sq. in. . . . .	. . . . .	. . . . .	6	3½-4	9-10
H	Slag	Production per ton pig.	Lb. . . . .	. . . . .	2800	2745	2464
		Analysis. %	{	SiO ₂	30.0	30.3	32.0
				CaO	48.0	44.8	40.0
				Al ₂ O ₃	13.7	16.2	18.0
				MgO	4.2	2.5	7.0
				S	...	...	...
				FeO	1.4	2.0	0.5
				MnO	1.0	2.0	1.8
J	Gas	Analysis. %	{	CO ₂	10.4	7.5	11.0
				CO	27.5	28.0	28.0
				H ₂	1.5	1.3	3.0
				N ₂	60.6	63.2	58.0
		Temperature. ° F. . . . .	. . . . .	. . . . .	300	550	450
K	Iron produced.	Lb. per sq. ft. of hearth area per hr.	. . . . .	. . . . .	136.7	67.9	141.3
L	Slag produced.	Lb. per sq. ft. of hearth area per hr.	. . . . .	. . . . .	170.9	83.2	155.5
M	Carbon gasified at tuyeres.	Lb. per sq. ft. of hearth area per hr.	. . . . .	. . . . .	133.1	71.4	108.0
N	Equivalent carbon (including sensible heat in blast).	Lb. per sq. ft. of hearth area per hr.	. . . . .	. . . . .	175.4	91.8	142.2
O	External loss requirements—as lb. of equivalent carbon per sq. ft. of hearth area per hr.	. . . . .	. . . . .	. . . . .	45.5	50.0	40.0
P	Slag requirements—as lb. of equivalent carbon per sq. ft. of hearth area per hr.	. . . . .	. . . . .	. . . . .	47.8	23.3	43.5
Q	Iron factor (including silicon)	. . . . .	. . . . .	. . . . .	0.600	0.273	0.415
R	Iron factor (excluding silicon)	. . . . .	. . . . .	. . . . .	0.506	0.200	0.295

(continued).

28.	29.	30.	31.	32.	33.	34.	35.	36.	A
88' 6"	83' 6"	60' 8"	75' 0"	87' 0"	80' 0"	80' 6"	87' 0"	71' 0"	B
13' 0"	13' 6"	10' 2"	11' 0"	13' 6"	12' 6"	13' 0"	14' 0"	11' 0"	
21' 0"	21' 9"	17' 0"	18' 0"	20' 0"	20' 3"	21' 6"	22' 0"	20' 0"	
11' 6"	15' 2"	12' 6"	14' 0"	10' 8½"	13' 6"	14' 6"	13' 0"	13' 6"	
1400 Foundry	1500 Basic	1000 Hema- tite	2000 Hema- tite	2100 Hema- tite	1700 Special hematite	1400 Basic	2900 Bessemer hematite	1050 Basic	C
2.25	1.31	2.00	2.00	1.75	1.50	-3.50	1.60	2.00	1.50
0.08	0.10	0.07	0.07	0.05	0.01	-0.02	0.038	0.06	0.041
1.40	2.27	0.103	0.10	0.06	0.018	-0.02	0.368	0.055	1.58
0.60	1.40	1.30	1.3	1.25	0.50	-0.75	1.53	1.00	1.56
3.50	3.10	3.70	3.70	3.80	3.80	-3.95	4.00	3.50	3.70
2577 Good	2360 Good	2353 Hard and dense	2240 Hard and dense	2104 Good	2352 Good. Hard	2374 Good. Hard	2142 Reasonably hard	2857 Moderate	D
86.0	86.0	80.0	80.0	84.0	87.0	83.5	86.0	84.2	
9.0	10.0	11.0	11.0	11.5	9.0	9.5	11.0	10.0	
4.5	3.5	7.0	7.0	4.0	3.0	5.0	3.0	4.6	
...	
...	419	560-1344	560-1344	736	560	627	905	...	E
58.5	37.7	35.44	35.44	39.32	35	38.3	36.32 Scrap 1.29	52.4	F
1305 6½	1400 11	1200 7	1200 11-13	1400 10-12	1200 10-11	1300 8½	1100 13	940 6.5	G
3248	1905	1232	1232	1232	1680	1344	1120	2520	H
32.0	33.2	36.4	36.4	33.0	32.0	28.10	37.00	32.80	
36.0	38.2	42.2	42.2	42.5	51.0	38.64	43.00	45.10	
28.0	18.0	12.8	12.8	13.0	10.9	19.34	15.00	15.50	
...	5.4	2.4	2.4	6.5	3.4	5.29	2.00	2.25	
...	
...	1.4	0.6	0.60	...	0.5	1.67	Trace	0.91	
...	2.2	1.6	1.6	...	0.7	0.93	1.00	1.16	
9.5	7.6	11.0	11.0	12.5	9.6	9.0	11.0	8.65	J
29.5	30.4	27.0	27.0	23.0	30.0	32.0	24.0	28.65	
1.0	2.7	2.0	2.0	2.0	1.9	0.8	3.0	3.00	
60.0	59.3	60.0	60.0	62.5	58.5	58.2	62.0	59.7	
610	850	600	600	400	450	500	500	350	
140.6	139.8	166.7	280.3	195.6	184.7	140.5	250.0	147.2	K
203.9	118.9	91.7	154.1	107.6	138.5	84.3	125.5	165.6	L
117.7	104.9	114.0	180.5	123.8	140.0	102.4	167.2	135.1	M
166.5	151.5	157.2	249.0	178.7	193.2	144.6	225.6	175.1	N
38.5	37.0	49.1	45.5	33.3	40.0	38.5	35.7	45.5	O
57.1	33.3	25.7	43.1	30.1	38.8	23.6	35.1	46.4	P
0.504	0.581	0.494	0.536	0.590	0.620	0.587	0.617	0.565	Q
0.234	0.424	0.254	0.296	0.394	...	0.395	0.377	0.385	R

APPENDIX III.

A		Furnace No.		38.	39.	40.
B	Furnace lines	Height		72' 0"	56' 0"	77' 0"
		Hearth diameter		12' 0"	8' 0"	11' 0"
		Bosh diameter		20' 0"	18' 0"	19' 0"
		Bosh height		12' 7"	12' 4"	12' 0"
C	Pig iron	Output per week. Tons		973	575	900
		Character		Foundry and forge	Foundry No. 3	Basic
				Si 3.04	2.75	0.75
				S 0.008	0.022	0.08
		Analysis. %		P 1.63	0.95	2.25
				Mn 0.21	1.55	2.50
D	Coke			C 3.25	3.50	3.00
		Consumption per ton pig. Lb.		3462	2960	2912
		Character		Moderate	Lumpy. Poor	Hard and dense
				Fixed carbon 77.2	75.58	82.00
		Average analysis. %		Ash 10.1	13.62	10.00
E	Limestone			Moisture 10.3	5.33	5.00
				Sulphur 1.3	1.77	2.00
		Consumption per ton pig. Lb.		1497	...	1904
F	Ore	Consumption per ton pig. Cwt.		58.04	57.28	51.31
G	Blast	Temperature. ° F.		1175	1350	900
		Pressure. Lb. per sq. in. . . . .		...	4½	7
H	Slag	Production per ton pig. Lb.		3025	2070	3250
				SiO ₂ 30.30	27.6	30.10
				CaO 41.86	48.10	45.28
				Al ₂ O ₃ 18.24	17.56	14.44
		Analysis. %		MgO 6.69	1.65	2.77
				S 1.78	2.78	...
				FeO ...	...	0.77
				MnO ...	0.50	1.58
J	Gas			CO ₂ 7.96	9.40	9.0
		Analysis. %		CO 29.04	30.80	28.0
				H ₂ 2.71	...	3.0
		Temperature. ° F.		N ₂ 59.95	...	60.0
K	Iron produced.			...	...	...
		Lb. per sq. ft. of hearth area per hr.		114.6	152.5	126.1
L	Slag produced.	Lb. per sq. ft. of hearth area per hr.		154.8	140.9	183.0
M	Carbon gasified at tuyeres.	Lb. per sq. ft. of hearth area per hr.		119.0	132.5	114.7
N	Equivalent carbon (including sensible heat in blast).					
		Lb. per sq. ft. of hearth area per hr.		163.4	189.2	147.6
O	External loss requirements—as lb. of equivalent carbon per sq. ft. of hearth area per hr.			41.7	62.5	45.5
P	Slag requirements—as lb. of equivalent carbon per sq. ft. of hearth area per hr.			43.4	39.5	51.2
Q	Iron factor (including silicon)			0.683	0.572	0.404
R	Iron factor (excluding silicon)			0.318	0.222	0.314

(continued).

41.	42.	43.	44.	45.	46.	47.	48.	49.	A
77' 0"	63' 6"	63' 6"	63' 6"	64' 0"	66' 0"	87' 0"	...	70' 0"	B
11' 0"	11' 0"	11' 0"	11' 0"	10' 0"	10' 0"	15' 6"	14' 0"	10' 0"	
19' 0"	20' 0"	20' 0"	20' 0"	24' 0"	17' 0"	19' 6"	...	16' 0"	
12' 0"	16' 6"	16' 6"	16' 6"	18' 6"	21' 0"	11' 4"	...	11' 3"	
900 Basic	979.5 Basic	888.5 Foundry	997 Foundry	590 Foundry	650 Foundry	3300 Hematite	1907 Special	1100 Basic and forge	C
0.75	1.2	3.4	3.25	1.5-2.5	3.0	1.5-2.0	1.96	0.8-1.5	
0.08	0.068	0.02	0.02	...	0.03	0.03	0.0146	...	
2.25	...	...	...	...	1.6	0.07	0.0199	...	
2.00	...	...	...	...	0.35	0.9	0.60	...	
3.00	...	...	...	...	...	...	...	...
3160 Hard and dense 50% 50% Mod.	2815 50% Good.	4095 33% Good.	3556 33% Good.	3370 Mod.	3100 Mod.	2070 Rather friable	2026 Mod.	2465 Mod.	D
82.00	77.0	81.5	81.5	83.0	81.0	85.07	85.83	80.5	
10.00	10.8	10.2	10.2	11.0	10.5	9.00	9.13	10.9	
5.00	9.5	5.7	5.7	4.0	6.0	5.00	2.05	6.3	
2.00	1.2	1.3	1.3	1.5	1.5	0.90	1.32	1.25	
1477	869	907	771	1610	1904	784	1018	672	E
46.72	53.38	52.08	55.00	45	55	37.5	35.93	52.0	F
850 7	1211 8½	1100 8½	1200 8½	1250 7½	1250 5-6	1200 12-14	1525 10½	1350 6-9	G
2910	2240	2240	2240	2912	2352	1400	1232	1680	H
31.10	29.27	26.67	28.23	29.0	30.50	31.86	31.22	30.0	
45.60	41.49	43.53	41.81	43.0	39.65	42.00	52.10	41.0	
13.08	20.24	21.90	23.16	21.0	21.00	16.23	10.57	17.0	
2.95	3.50	3.50	3.50	5.0	2.53	7.25	...	4.0	
...	...	...	...	...	2.20	...	2.73	...	
0.42	...	...	...	...	1.00	...	...	...
1.49	...	...	...	...	0.37	...	...	...
9.0	10.0	6.45	9.3	...	...	11.53	...	...	J
28.0	28.7	29.80	29.1	...	...	27.15	...	...
3.0	2.5	4.10	2.8	...	...	2.16	...	...
60.0	58.7	59.65	58.9	...	...	59.25	...	...
...	384	776	565	...	...	...	...	...
126.1	137.3	124.6	139.8	100.0	110.3	233.0	165.1	186.6	K
163.9	137.3	124.6	139.8	130.1	115.9	145.7	90.8	140.0	L
126.1	111.4	166.1	159.0	109.4	106.4	147.2	102.4	136.1	M
160.1	154.2	224.0	219.5	152.6	148.5	203.1	149.8	194.4	N
45.5	45.5	45.5	45.5	50.0	50.0	32.3	35.7	50.0	O
45.9	38.4	34.9	39.2	36.4	32.5	40.8	25.4	39.2	P
0.541	0.512	1.152	0.964	0.662	0.598	0.558	0.537	0.564	Q
0.451	0.368	0.744	0.574	0.422	0.238	0.342	0.302	0.43	R

A		Furnace No.		50.	51.	53.
B	Furnace lines	Height		67' 0"	67' 0"	79'
		Hearth diameter		9' 0"	9' 0"	12.45'
		Bosh diameter		16' 5"	16' 5"	24'
		Bosh height		15' 5"	15' 5"	16.4'
C	Pig iron	Output per week. Tons		460	460	1905
		Character		Hema- tite	Hema- tite	Basic
		Analysis. %	Si	2.60	2.08	0.29
			S	...	...	0.06
			P	...	...	2.24
			Mn	...	...	1.64
			C	...	...	3.50
D	Coke	Consumption per ton pig. Lb. .	...	...	...	2079
		Character	90% coal + coke	90% coal + coke	Good	
		Average analysis. %	Fixed carbon	...	...	80.0
			Ash	...	...	10.8
			Moisture	...	...	6.7
			Sulphur	...	...	...
E	Limestone	Consumption per ton pig. Lb. .	549	549	365	
F	Ore	Consumption per ton pig. Cwt.	33.66	33.66	41.85	
G	Blast	Temperature. ° F.	1500	1500	1115	
		Pressure. Lb. per sq. in. . .	5	5	7 $\frac{3}{4}$	
H	Slag	Production per ton pig. Lb. .	800	825	1389	
		Analysis. %	SiO ₂	28.0	28.0	...
			CaO	50.0	50.0	...
			Al ₂ O ₃	15.0	15.0	...
			MgO	...	...	...
			S	2.3	2.3	...
			FeO	...	...	...
			MnO	...	...	...
J	Gas	Analysis. %	CO ₂	...	...	9.7
			CO	...	...	29.6
			H ₂	...	...	1.8
			N ₂	...	...	58.6
		Temperature. ° F. . . . .	...	...	390	
K	Iron produced.	Lb. per sq. ft. of hearth area per hr.	96.4	100.2	208.2	
L	Slag produced.	Lb. per sq. ft. of hearth area per hr.	34.4	37.0	129.1	
M	Carbon gasified at tuyeres.	Lb. per sq. ft. of hearth area per hr.	67.0	74.2	122.1	
N	Equivalent carbon (including sensible heat in blast).	Lb. per sq. ft. of hearth area per hr.	98.9	109.5	164.8	
O	External loss requirements—as lb. of equivalent carbon per sq. ft. of hearth area per hr.		55.6	55.6	40.2	
P	Slag requirements—as lb. of equivalent carbon per sq. ft. of hearth area per hr.		9.6	10.4	36.1	
Q	Iron factor (including silicon)	. . . . .	0.350	0.434	0.425	
R	Iron factor (excluding silicon)	. . . . .	0.038	0.184	0.390	

(continued).

54.	55.	56.	57.	58.	59.	60.	61.	62.	A
70'	88'	94'	88'	70'	85'	79'	67'	79'	B
14.75'	13.75'	17.05'	13.75'	14.75'	16.4'	12.45'	10.5'	13.5'	
24'	23.6'	23'	23.5'	24'	25.5'	24'	21.5'	24'	
14.25'	14.75'	14.75'	14.75'	14.25'	14'	16.5'	16.5'	14.75'	
3032	2269	4815	2530	3348	4815	1691	1031	1581	C
Basic	Basic	Basic	Basic	Basic	Basic	Basic	Foundry	Foundry	
0.26	...	0.30	...	0.42	0.35	1.95	3.0	2.50	
0.092	0.08	0.09	0.08	0.113	0.065	0.02	0.028	0.025	
2.05	2.10	2.15	2.10	1.82	2.10	0.06	0.70	0.70	
1.55	1.80	1.65	1.80	1.60	1.35	4.05	0.70	0.70	
3.50	3.50	3.60	3.50	3.50	3.40	4.00	4.00	3.70	
2195	2415	2128	2520	2195	2465	2465	2575	3025	D
Good	...	...	...	...	...	...	...	...
80.6	77.5	79.5	77.5	81.3	79.0	81.3	78.5	78.0	
8.6	11.5	10.5	11.5	8.8	10.0	8.8	9.5	10.0	
8.3	7.5	7.5	7.5	7.4	9.0	7.4	11.0	10.0	
...	
273	346	88	440	346	...	970	616	...	E
47.00	52.3	43.0	56.1	41.65	44.45	46.3	44.75	54.1	F
1145	1095	1075	1095	1125	1185	1190	1380	1245	G
8 $\frac{3}{4}$	12 $\frac{1}{2}$	14 $\frac{1}{4}$	12 $\frac{1}{2}$	10	7 $\frac{3}{4}$ -15 $\frac{1}{2}$	10 $\frac{1}{2}$	6 $\frac{1}{4}$	6 $\frac{1}{2}$	
1500	2015	1299	2015	1345	2240	2150	1389	2240	H
...	
...	
...	
...	
...	
...	
...	
7.0	8.0	7.0	8.0	7.5	7.85	10.9	6.0	6.1	J
32.6	31.2	31.5	31.2	31.9	29.00	28.5	33.0	30.0	
2.0	2.5	2.3	2.5	1.8	2.00	1.5	...	2.7	
58.3	58.2	58.9	58.2	58.4	60.00	58.7	...	61.2	
670	...	...	...	445	...	390	...	...
236.5	203.8	281.5	227.1	261.0	304.2	185.3	158.8	155.1	K
158.4	183.2	163.3	204.2	156.8	304.2	177.9	98.5	155.1	L
150.0	138.2	168.4	162.8	167.2	217.0	136.9	118.4	139.1	M
204.2	186.1	226.0	219.2	226.8	298.2	188.5	170.2	194.1	N
33.9	36.4	29.3	36.4	33.9	30.5	40.2	47.6	38.0	O
44.4	51.3	45.7	57.2	43.9	85.2	49.8	27.6	43.4	P
0.533	0.483	0.536	0.553	0.571	0.600	0.531	0.598	0.727	Q
0.502	...	0.500	...	0.520	0.558	0.297	0.238	0.427	R

APPENDIX III.

A		Furnace No.		63.	64.	65.
B	Furnace lines	Height		66'	79'	79'
		Hearth diameter		11·15'	13·15'	12·45'
		Bosh diameter		21·5'	24'	24'
		Bosh height		18·75'	14·75'	16·4'
C	Pig iron	Output per week. Tons		1684	1718	1677
		Character		Foundry	Hema- tite	Hema- tite
		Analysis. %	Si	2·47	2·80	2·06
			S	0·031	0·03	0·026
			P	0·97	0·09	0·07
			Mn	0·77	0·90	0·77
			C	3·60	3·70	4·00
D	Coke	Consumption per ton pig. Lb.		2690	2800	2425
		Character . . . . .		...	...	...
		Average analysis. %	Fixed carbon	82·4	78·0	80·6
			Ash	8·5	10·0	8·6
			Moisture	7·7	10·0	8·3
			Sulphur	...	...	...
E	Limestone	Consumption per ton pig. Lb.		475	...	930
F	Ore	Consumption per ton pig. Cwt.		46·75	46·0	44·0
G	Blast	Temperature. ° F.		1405	1245	1300
		Pressure. Lb. per sq. in.		7½	6½	9½
H	Slag	Production per ton pig. Lb.		1332	1455	1927
		Analysis. %	SiO ₂	...	...	...
			CaO	...	...	...
			Al ₂ O ₃	...	...	...
			MgO	...	...	...
			S	...	...	...
			FeO	...	...	...
J	Gas	Analysis. %	CO ₂	5·99	6·1	10·3
			CO	33·21	30·0	29·0
			H ₂	2·02	2·7	1·6
			N ₂	58·49	61·2	58·8
		Temperature. ° F. . . . .		...	...	480
K	Iron produced.	Lb. per sq. ft. of hearth area per hr.		229·8	168·6	183·6
L	Slag produced.	Lb. per sq. ft. of hearth area per hr.		136·7	109·5	158·0
M	Carbon gasified at tuyeres.	Lb. per sq. ft. of hearth area per hr.		191·9	138·1	131·6
N	Equivalent carbon (including sensible heat in blast).	Lb. per sq. ft. of hearth area per hr.		277·5	192·6	185·9
O	External loss requirements—as lb. of equivalent carbon per sq. ft. of hearth area per hr.			44·8	38·0	40·2
P	Slag requirements—as lb. of equivalent carbon per sq. ft. of hearth area per hr.			38·6	30·7	44·2
Q	Iron factor (including silicon)			0·845	0·735	0·553
R	Iron factor (excluding silicon)			0·548	0·400	0·306

(continued).

66.	67.	68.	69.	70.	71.	72.	75.	76.	A
79'	57'	79'	57'	74'	63'	77'	80' 0"	80' 0"	B
12.45'	14.75'	12.45'	14.75'	13.15'	11.5'	12.8'	16' 0"	16' 0"	
24'	20.5'	24'	20.5'	20.5'	19.75'	23.0'	22' 0"	22' 0"	
16.4'	12.2'	16.4'	12.2'	15.5'	12.8'	16.4'	12' 3"	12' 3"	
1334	1588	1766	2090	3060	866	3093	4185	3820	C
Low man- ganese	Hema- tite	...	...	...	...	...	...	...
2.3	2.2	0.75	0.32	0.65	0.80	0.60	1.37	1.14	
0.02	0.039	0.02	0.042	0.04	0.054	0.04	1.031	0.030	
0.08	0.12	0.18	0.147	0.12	0.33	0.25	0.084	0.084	
0.42	0.72	3.43	3.87	4.25	2.70	2.75	0.71	0.73	
4.00	4.17	3.85	4.00	4.25	4.00	4.00	...	...
2380	3025	2308	2530	2465	2430	2030	1907	1892	D
...	
81.1	78.8	81.3	82.1	79.0	80.5	84.5	86.2	86.2	
9.8	8.3	8.8	8.6	10.0	15.0	8.5	12.0	12.0	
6.6	11.2	7.4	7.6	9.0	6.0	5.5	...	...
...	...	...	...	...	...	...	0.90	0.98	
823	1145	1024	1000	...	1100	1180	802	896	E
36.1	43.6	49.4	47.2	38.1	51.6	50.0	34.7	33.5	F
1325	1435	950	1365	1185	1290	1380	980	950	G
10	7½	9½	7½	7½-15	4½-5½	11½	...	...
1612	...	2690	1470	2240	1792	1737	905	985	H
...	...	...	...	...	...	...	32.6	33.7	
...	...	...	...	...	...	...	46.5	46.5	
...	...	...	...	...	...	...	15.7	15.4	
...	...	...	...	...	...	...	2.3	3.2	
...	...	...	...	...	...	...	1.30	1.22	
...	...	...	...	...	...	...	0.95	0.90	
...	...	...	...	...	...	...	0.43	0.61	
7.2	5.0	11.3	5.3	7.9	9.5	6.6	13.2	12.7	J
32.6	33.8	28.7	34.3	29.0	30.0	33.1	26.4	25.8	
1.4	1.7	1.2	2.2	2.0	2.9	2.4	2.3	2.6	
58.2	59.3	58.5	58.0	60.0	...	57.8	59.0	58.9	
480	...	390	...	...	480	...	263	312	
146.1	123.9	193.5	163.0	300.0	111.6	321.0	277.7	253.6	K
105.2	...	232.3	106.9	300.0	89.3	248.9	112.2	111.5	L
103.1	112.2	132.0	125.5	214.1	80.0	195.5	160.6	145.0	M
146.4	163.3	171.7	180.0	294.5	112.6	281.0	210.3	188.6	N
40.2	33.9	40.2	33.9	38.0	43.5	39.1	31.3	31.3	O
29.5	...	65.0	30.0	84.0	25.0	69.7	31.4	31.2	P
0.525	...	0.344	0.712	0.575	0.395	0.536	0.532	0.497	Q
0.249	...	0.254	0.676	0.497	0.299	0.464	0.368	0.360	R

A	Furnace No.		77.	78.	79.
B	Furnace lines	Height	88' 0"	90' 0"	80'
		Hearth diameter	18' 0"	17' 0"	15.5'
		Bosh diameter	22' 0"	22' 0"	22'
		Bosh height	11' 0"	12' 3"	12.5'
C	Pig iron	Output per week. Tons	3674	4072	3632
		Character . . . . .	...	...	...
		Analysis. %	Si 0.97	1.29	1.27
			S 0.044	0.049	0.036
			P 0.244	0.095	0.200
			Mn 0.18	0.65	...
C	...	...	...
D	Coke	Consumption per ton pig. Lb.	1958	2070	2040
		Character . . . . .	...	...	...
		Average analysis. %	Fixed carbon 84.9	85.3	85.4
			Ash 10.3	13.2	13.2
		Moisture	...	...
		Sulphur 0.76	1.20	1.14	
E	Limestone	Consumption per ton pig. Lb.	785	1310	956
F	Ore	Consumption per ton pig. Cwt.	39.3	39.9	36.5
G	Blast	Temperature. ° F.	1020	1025	890
		Pressure. Lb. per sq. in. . . . .	...	...	...
H	Slag	Production per ton pig. Lb.	885	1390	1086
		Analysis. %	SiO ₂ 34.8	35.0	32.7
			CaO 45.7	48.3	40.9
			Al ₂ O ₃ 14.1	13.0	14.1
			MgO 2.3	2.2	9.4
			S 1.66	1.74	...
			FeO 0.35	...	...
			MnO 1.20	...	...
J	Gas	Analysis. %	CO ₂ 11.7	12.9	13.0
			CO 26.5	25.2	26.0
			H ₂ 3.2	2.6	3.1
			N ₂ 58.6	59.3	57.9
		Temperature. ° F.	296	352	354
K	Iron produced. Lb. per sq. ft. of hearth area per hr.	192.5	239.2	256.8	
L	Slag produced. Lb. per sq. ft. of hearth area per hr.	76.0	148.5	124.5	
M	Carbon gasified at tuyeres. Lb. per sq. ft. of hearth area per hr.	112.8	151.2	159.6	
N	Equivalent carbon (including sensible heat in blast). Lb. per sq. ft. of hearth area per hr.	149.1	200.3	204.8	
O	External loss requirements—as lb. of equivalent carbon per sq. ft. of hearth area per hr.	27.8	29.4	32.3	
P	Slag requirements—as lb. of equivalent carbon per sq. ft. of hearth area per hr.	21.3	41.6	34.9	
Q	Iron factor (including silicon)	0.520	0.530	0.536	
R	Iron factor (excluding silicon)	0.404	0.375	0.384	

(continued).

80.	81.	82.	83.	84.	85.	86.	87.	88.	A
92.5'	90'	95'	90'	85'	85'	88'	...	86'	B
16.6'	17'	17.7'	17.3'	17.3'	16'	17.3'	17'	14.5'	
22'	22'	22'	22'	22'	21'	21.5'	...	19.7'	
11.5'	...	12'	13'	13'	12.25'	12'	...	12.75'	
3807	3863	3878	3813	3632	3969	3340	3626	1806	C
...	
1.59	1.12	0.96	1.27	1.70	1.51	1.43	1.18	2.5	
0.032	0.033	0.049	0.034	0.041	0.035	0.038	0.041	...	
0.085	0.324	0.206	0.131	0.084	0.100	0.250	0.225	...	
0.80	1.84	1.62	1.34	0.71	0.68	1.03	1.68	...	
...	
1704	2000	2085	1720	1950	2450	2158	2213	3160	D
...	
88.1	88.9	85.4	88.3	88.2	85.3	84.9	84.9	85.6	
11.0	10.7	13.0	11.0	11.2	13.0	10.3	10.3	10.5	
...	...	...	...	...	...	...	...	2.5	
0.82	0.61	1.18	0.82	0.82	1.18	0.76	0.76	0.9	
723	889	1223	793	732	1267	839	753	1700	E
28.6	39.6	39.3	31.1	30.6	39.9	37.6	35.9	42.7	F
								Scrap 1	
1105	825	1000	1006	944	1150	1100	1183	1100	G
...	
800	1222	1470	910	910	1365	1020	900	1700	H
36.0	35.8	34.0	34.2	37.1	34.9	36.0	33.7	...	
38.9	44.5	46.1	43.0	36.5	48.5	43.6	44.2	...	
15.5	12.4	14.7	17.2	16.0	13.1	13.3	15.3	...	
7.3	5.7	3.5	2.30	7.1	2.0	4.8	3.8	...	
1.70	1.29	1.81	1.43	1.83	1.62	1.33	1.68	...	
...	0.63	0.90	...	...	0.95	0.33	0.39	...	
...	...	...	...	...	...	0.56	1.69	...	
13.2	12.8	14.5	14.9	12.6	12.5	12.2	12.4	8.5	J
26.4	24.4	25.3	24.5	26.6	15.9	27.0	26.8	30.1	
3.8	2.3	1.1	3.7	3.8	1.4	3.0	3.5	2.8	
56.6	60.5	59.1	56.9	57.0	60.2	57.8	57.3	58.6	
325	425	232	308	278	457	377	380	450	
234.7	227.0	210.0	216.5	206.2	263.2	189.5	213.0	145.8	K
83.8	123.9	137.8	88.0	83.8	160.5	86.3	85.6	110.6	L
120.5	144.6	134.0	112.9	126.1	204.7	125.2	145.3	153.4	M
163.0	182.5	176.5	148.8	163.9	279.0	169.0	199.8	206.8	N
30.1	29.4	28.3	28.9	28.9	31.3	28.9	29.4	34.5	O
23.5	34.7	38.6	24.6	23.5	45.0	24.2	24.0	31.0	P
0.466	0.522	0.522	0.440	0.540	0.770	0.611	0.687	0.969	Q
0.275	0.388	0.407	0.288	0.336	0.589	0.439	0.545	0.669	R

A		Furnace No.	89.	90.	91.
B	Furnace lines	Height	79'	66'	84' 0"
		Hearth diameter	12·3'	12·8'	16' 0"
		Bosh diameter	17·8'	19·6'	20' 0"
		Bosh height	12·5'	16'	11' 0"
C	Pig iron	Output per week. Tons	1820	2927	2485
		Character . . . . .	...	...	...
		Analysis. %	Si 2·8	1·1	3·0
			S ...	...	...
			P ...	...	...
			Mn ...	...	...
			C ...	...	...
D	Coke	Consumption per ton pig. Lb.	2800	1900	2645
		Character . . . . .	...	...	...
		Average analysis. %	Fixed carbon 82·4	87·3	87·2
			Ash 13·5	8·0	11·3
			Moisture 3·0	3·6	0·5
			Sulphur 0·8	1·1	1·3
E	Limestone	Consumption per ton pig. Lb.	950	476	...
F	Ore	Consumption per ton pig. Cwt.	46·4	34·1	50·5
		Scrap	1·2	9·0	1·2
G	Blast	Temperature. ° F.	1180	1100	1150
		Pressure. Lb. per sq. in. . . . .	...	...	...
H	Slag	Production per ton pig. Lb.	2800	1200	1900
		Analysis. %	SiO ₂ ...	...	...
			CaO ...	...	...
			Al ₂ O ₃ ...	...	...
			MgO ...	...	...
			S ...	...	...
			FeO ...	...	...
			MnO ...	...	...
J	Gas	Analysis. %	CO ₂ 9·3	7·7	8·2
			CO 32·4	32·7	32·1
			H ₂ 2·8	2·1	3·0
			N ₂ 55·6	57·5	56·7
		Temperature. ° F.	450	600	500
K	Iron produced.	Lb. per sq. ft. of hearth area per hr.	203·9	303·8	164·9
L	Slag produced.	Lb. per sq. ft. of hearth area per hr.	254·8	162·7	139·9
M	Carbon gasified at tuyeres.	Lb. per sq. ft. of hearth area per hr.	178·1	177·5	144·1
N	Equivalent carbon (including sensible heat in blast).	Lb. per sq. ft. of hearth area per hr.	244·8	239·5	196·5
O	External loss requirements—as lb. of equivalent carbon per sq. ft. of hearth area per hr.		40·7	39·1	31·2
P	Slag requirements—as lb. of equivalent carbon per sq. ft. of hearth area per hr.		71·4	45·9	39·2
Q	Iron factor (including silicon)		0·651	0·509	0·765
R	Iron factor (excluding silicon)		0·315	0·377	0·405

(continued).

92.	93.	94.	95.	96.	97.	98.	99.	100.	A
85' 0"	83' 0"	95'	100'	100'	85'	90'	90'	...	B
13' 0"	17' 0"	19'	18'	18'	17'	13·5'	13·5'	12·2'	
20' 0"	22' 0"	22·5'	22'	22'	20·5'	21'	21'	...	
12' 0"	14' 0"	10'	12·5'	9·5'	9·5'	13'	13'	...	
2492	3330	4025	3142	3598	3605	2506	3130	2212	C
...	
2·8	1·1	1·3	1·4	1·2	1·2	1·0	1·0	2·52	
...	...	...	...	...	...	...	...	0·028	
...	...	...	...	...	...	...	...	0·75	
...	
...	
2765	2750	1700	2465	2300	1770	2147	1726	2690	D
...	
86·8	87·5	85·8	82·7	81·3	82·3	85·0	85·0	85·1	
11·7	7·9	10·8	14·2	12·3	11·3	...	...	13·2	
0·5	3·5	2·0	2·0	4·7	5·1	...	...	5·75	
1·1	1·1	0·9	1·1	1·1	0·9	...	...	0·76	
134	330	1060	1466	1358	916	1072	1015	402	E
51·0	49·4	39·7	39·1	39·8	35·6	38·3	36·3	47·8	F
Scrap	Scrap		Scrap	Scrap	Scrap				
1·0	1·0		1·0	0·7	2·6				
1200	1175	1100	1000	900	1000	720	870	1325	G
...	
2200	2200	1500	2000	1700	1500	1000	1000	2030	H
...	...	...	...	...	...	...	...	38·47	
...	...	...	...	...	...	...	...	47·13	
...	...	...	...	...	...	...	...	13·43	
...	
...	
...	
...	
...	
7·5	...	16·0	10·8	...	15·1	...	...	...	J
33·4	...	25·0	27·7	...	25·8	...	...	...
2·6	...	3·0	3·5	...	3·3	...	...	...
56·5	...	56·0	58·0	...	55·8	...	...	...
365	500	400	355	430	230	...	...	...
250·2	195·8	189·3	164·6	188·5	211·8	233·2	291·5	253·2	K
245·8	192·2	126·8	147·0	143·1	141·9	104·0	130·0	229·5	L
229·0	197·7	93·6	124·2	127·9	104·6	153·6	145·4	219·0	M
316·0	246·3	126·3	163·6	164·3	157·7	188·6	185·5	311·0	N
38·5	29·4	26·3	27·8	27·8	29·4	37·0	37·0	41·1	O
68·8	53·8	53·5	41·2	40·1	39·7	29·1	36·4	64·3	P
0·834	0·833	0·341	0·574	0·511	0·324	0·525	0·385	0·811	Q
0·498	0·700	0·185	0·406	0·367	0·180	...	...	0·509	R

APPENDIX III.

A		Furnace No.		101.	102.	103.
B	Furnace lines	Height		79'	75'	76'
		Hearth diameter		11.5'	11.5'	14.1'
		Bosh diameter		20.3'	21.3'	20.7'
		Bosh height		16'	15.75'	...
C	Pig iron	Output per week.	Tons	1444	1616	2575
		Character		Basic	Basic	White iron
		Analysis. %	Si	0.36	0.32	...
			S	0.07	0.06	...
			P	2.18	2.17	...
			Mn	1.40	1.36	...
			C	...	...	...
D	Coke	Consumption per ton pig.	Lb.	2028	2015	1691
		Character		Medium	Medium	...
		Average analysis. %	(Fixed carbon	79.87	80.49	82.0
			Ash	10.45	10.58	18.0 {
			Moisture	7.10	6.24	
			Sulphur	1.16	1.17	
E	Limestone	Consumption per ton pig.	Lb. . . . .	...	...	510
F	Ore	Consumption per ton pig.	Cwt.	48.9	48.9	31.3 Scrap 1.93
G	Blast	Temperature. ° F.		1725	1470	1380
		Pressure. Lb. per sq. in. . . . .		...	...	9.3-10.2
H	Slag	Production per ton pig.	Lb.	1288	1288	960
		Analysis. %	SiO ₂	28.97	28.65	...
			CaO	45.22	46.39	...
			Al ₂ O ₃	16.83	16.64	...
			MgO	4.46	4.03	...
			S	1.56	1.56	...
			FeO	(Fe)0.67	(Fe)0.69	...
			MnO	2.13	1.95	...
J	Gas	Analysis. %	CO ₂	12.0	12.0	10.4
			CO	26.0	26.0	28.9
			H ₂	...	...	2.1
			N ₂	...	...	56.8
		Temperature. ° F. . . . .		...	...	300-570
K	Iron produced.	Lb. per sq. ft. of hearth area per hr.		185.5	207.2	219.8
L	Slag produced.	Lb. per sq. ft. of hearth area per hr.		106.6	119.2	94.2
M	Carbon gasified at tuyeres.	Lb. per sq. ft. of hearth area per hr.		105.0	117.7	101.8
N	Equivalent carbon (including sensible heat in blast).	Lb. per sq. ft. of hearth area per hr.		162.4	172.8	146.3
O	External loss requirements—as lb. of equivalent carbon per sq. ft. of hearth area per hr.			43.5	43.5	35.5
P	Slag requirements—as lb. of equivalent carbon per sq. ft. of hearth area per hr.			29.9	33.4	25.4
Q	Iron factor (including silicon)			0.480	0.463	0.384
R	Iron factor (excluding silicon)			0.437	0.425	...

A	Furnace No.		113.	114.	115.		
B	Furnace lines	Height	78'	88'	82'		
		Hearth diameter	14·76'	14·75'	11·48'		
		Bosh diameter	23·8'	25·9'	21·5'		
		Bosh height	19·7'	19·35'	14·92'		
C	Pig iron	Output per week. Tons	1719	1645	1031		
		Character	Basic	Foundry	Basic		
		Analysis. %	Si	0·45	2·0	3·5	0·578
			S	0·05	0·01	0·03	0·07
			P	1·78	0·7	1·7	1·814
			Mn	1·20	0·6	0·8	1·125
C		C	...	...	...
D	Coke	Consumption per ton pig. Lb.	2195	2875	2397		
		Character	Good	Good	Mod.		
		Average analysis. %	Fixed carbon	86·0	85·0	86·0	
			Ash	10·5	9·0	11·3	
			Moisture	3·0	4·0	1·0	
			Sulphur	
E	Limestone	Consumption per ton pig. Lb. . . . .	...	...	...
F	Ore	Consumption per ton pig. Cwt.	67·6	55·0	69·2		
G	Blast	Temperature. ° F.	1380	1520	1260		
		Pressure. Lb. per sq. in. . . . .	...	...	...
H	Slag	Production per ton pig. Lb.	2128	1792	2016		
		Analysis. %	SiO ₂	29·5	34·0	31·89	
			CaO	42·0	40·5	42·34	
			Al ₂ O ₃	18·0	17·5	17·39	
			MgO	
			S	1·17	
			FeO (Fe)	1·0	0·40	1·29	
			MnO	1·70	0·30	1·60	
J	Gas	Analysis. %	CO ₂	13·0	9·0	12·87	
			CO	26·0	29·5	27·86	
			H ₂	3·0	3·0	3·67	
			N ₂	58·0	56·0	55·60	
		Temperature. ° F.	176	300-390	375		
K	Iron produced.	Lb. per sq. ft. of hearth area per hr.	133·8	128·2	132·6		
L	Slag produced.	Lb. per sq. ft. of hearth area per hr.	127·1	102·6	119·4		
M	Carbon gasified at tuyeres.	Lb. per sq. ft. of hearth area per hr.	91·4	115·0	99·8		
N	Equivalent carbon (including sensible heat in blast).	Lb. per sq. ft. of hearth area per hr.	131·4	170·5	139·7		
O	External loss requirements—as lb. of equivalent carbon per sq. ft. of hearth area per hr.		33·8	33·9	43·6		
P	Slag requirements—as lb. of equivalent carbon per sq. ft. of hearth area per hr.		35·6	28·7	33·4		
Q	Iron factor (including silicon)	. . . . .	0·463	0·842	0·473	
R	Iron factor (excluding silicon)	. . . . .	0·409	0·512	0·404	

(continued).

117.	118.	119.	120.	121.	122.	123.	A
89'	89'	89'	89'	89'	55' 6"	55' 6"	B
17'	17'	17'	17'	17'	10' 0"	10' 0"	
21.5'	21.5'	21.5'	21.5'	21.5'	18' 0"	18' 0"	
11.7'	11.7'	11.7'	11.7'	11.7'	11' 2"	11' 2"	
4240	4310	4720	3510	4075	950	1190	C
Basic	Basic	Basic	Basic	Basic	Hema- tite	Hema- tite	
0.81	0.79	0.88	1.14	1.14	1.05	0.93	
0.034	0.033	0.045	0.038	0.041	0.042	0.043	
...	
1.38	1.39	1.37	0.53	0.50	1.63	1.78	
...	
2367	2302	2195	2419	2206	2520	2320	D
Good	Good	Good	Good	Good	Good	Good	
physi- cally	physi- cally	physi- cally	physi- cally	physi- cally			
70.0	70.0	70.0	70.0	70.0	82.01	87.27	
21.5	21.5	21.5	21.5	21.5	12.50	8.75	
7.5	7.5	7.5	7.5	7.5	3.10	1.48	
...	...	...	...	...	0.69	0.80	
1463	1398	1108	1531	1083	920	752	E
31.75	31.80	33.80	33.78	33.78	38.79	38.21	F
1155	1120	1157	1125	1181	1240	1300	G
...	...	...	...	...	4½	4½	
1565	1460	1236	1626	1248	1220	1000	H
29.65	28.45	30.73	28.56	29.86	30.80	30.10	
28.67	29.43	40.50	27.75	40.15	48.90	50.00	
19.71	19.31	20.80	21.66	20.80	11.60	11.43	
17.90	17.83	3.55	18.61	5.20	5.86	5.79	
...	...	...	...	...	2.62	2.51	
2.06	2.45	1.91	1.67	2.25	0.42	0.35	
1.11	1.32	1.70	0.72	0.77	0.99	1.32	
10.7	10.4	11.6	10.5	12.5	8.25	9.50	J
29.4	29.6	27.2	29.0	27.3	30.50	29.70	
1.0	0.8	0.9	0.8	0.8	3.15	2.19	
...	...	...	...	...	58.10	58.61	
...	...	...	...	...	625	700	
249.0	253.3	277.2	206.1	239.2	160.5	201.0	K
174.0	165.2	153.0	149.7	115.6	87.4	89.8	L
145.1	142.6	146.8	123.6	127.6	123.4	150.8	M
198.2	193.3	200.6	167.9	175.4	171.8	213.0	N
29.4	29.4	29.4	29.4	29.4	50.0	50.0	O
48.7	46.3	42.8	41.9	32.4	24.5	25.1	P
0.482	0.464	0.463	0.468	0.475	0.606	0.686	Q
0.395	0.369	0.357	0.331	0.338	0.480	0.574	R

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DISCUSSION.

Mr. A. K. REESE (Weybridge) said he had found much in the paper on which he should like to comment, but he was afraid that a good deal of what he had to say would be critical. It was not pleasant to criticise other men's work, but sometimes one had to do so in order to point out where fallacious conclusions might be drawn from it.

There was no doubt that the authors had done a big piece of work; they seemed to have gone all over the world to get their information about those 120 furnaces. They attempted to draw from it some sort of an average of the working data of all those furnaces from which they could construct a formula, the application of which to any furnace would indicate its degree of economy in fuel consumption. They included the most modern furnaces representative of American and German practice, and they also included a very considerable number of what might be called very indifferent types of furnaces, furnaces operated under old practice, with very few of the features incorporated in modern blast-furnace practice, which produced the results obtained in up-to-date operation. It seemed to him that to attempt to draw up a formula such as the authors had produced from an average of the results from so many different types of blast-furnaces (good, bad, and indifferent), working under such widely differing conditions and methods, was an attempt to show correlation between the uncorrelateable.

The authors appeared to have arrived at figures and conclusions somewhat arbitrarily, without explaining very clearly how they obtained them, and it was difficult to accept a formula such as they gave without that explanation. On p. 57, for example, they spoke of having dealt with only the essential features and of having eliminated all unimportant or minor features, but they said nothing about how they distinguished between them. Again, in the formula on p. 63 they gave figures without stating where they got them from. They gave 500 as representing the factor K , 0.56 for X , and 0.28 for Y . They simply stated that "over 120 reasonably reliable records of blast-furnace operation were available as a basis of investigation," and that from them they found those figures representing those factors. The factor for iron was just twice the factor for slag. Personally—and he thought there were others who would agree with him—he would like to know by what course of reasoning they arrived at those figures. He thought that information was necessary before the figures given could be accepted as being even reasonably correct.

It seemed to him that the authors' formula could not be in any way regarded as conclusive, any more than Johnson's data, which they alleged to be inconclusive.

Another point which was very noticeable throughout the paper was the great mass of assumptions made in arriving at the formula. The authors assumed a factor of 350 lb. for the coke not burnt at the tuyeres, and that was taken to be a constant for all furnaces. He did not want to enumerate all the assumptions, but there were a great many others, and it was not right to assume that a factor like that was a constant for all blast-furnaces. It was well known from the causes affecting that factor that there was a great variation in the amount of carbon not burnt at the tuyeres. There were the carbon solution losses at the top of the furnace, and the carbon that was deposited on the way down. Those reactions varied with the conditions of operation and with the kind of ore and coke used, and to assume a fixed figure for a formula such as the authors' seemed to him unwarranted.

There was a reference in the paper to blast-furnaces blown by pressure, and he was rather surprised at their inclusion in the paper. Although a certain number were still in operation they were certainly very much out of date. The results obtained and the quantitative reactions in those furnaces could not be correlated with similar features in furnaces operated by the modern method of blowing by volume. It seemed to him that the inclusion of blast-furnaces of that type in such an investigation introduced factors which would tend to destroy the practical value of the investigation.

In referring to the question of blowing by pressure on p. 72, the authors also said that if the pressure dropped the blast increased, the output increased, and the fuel consumption fell. On the other hand, if the manager of a blast-furnace were blowing by volume and his pressure fell he would, according to the authors, immediately put more burden on the furnace. There was a normal pressure in every furnace, and he did not think there were many blast-furnace operators who would think of immediately putting more burden on the furnace if the pressure began to fall, because as a rule that was an indication either that the furnace was getting cold or that some other abnormal action was taking place, and the manager would want to know the cause before he took any action. The reverse was the case if the pressure went up. Those little things were not indications to a blast-furnace manager to go and change the conditions in the furnace immediately, much less to increase the burden.

However sound or unsound the premise (the records of those 120 furnaces) on which the authors based their efforts at correlation, and however logical or otherwise the course of reasoning by which they had arrived at the factors in their formula, they had reached a number of conclusions; these, he was pleased to note, confirmed those features of blast-furnace practice to which he had many times referred as being essential if the best results were to be obtained. The authors had concluded that the preparation of materials was a very essential thing—

though they did not say of what that preparation consisted—and that the distribution was very important. They also said that the lines of the furnace and the coke quality were matters of great moment. That was all unquestionably quite true, but he could not agree that the authors' method justified those conclusions, though it afforded an instructive comparison of the results from the various furnaces.

He was of opinion that it would have been far more instructive if they had taken half a dozen completely modern furnaces with prepared materials, &c., half a dozen furnaces of the old type without prepared material, without modern lines, and so on, and another intermediate group; they could then have made a comparison of any factors they could derive from the records of those three sets of blast-furnaces operating under different conditions. In that way they could have compared the better factors from the more modern types with the poorer factors from the older and less well-equipped types of furnaces operated under old conditions.

Mr. D. SILLARS (Middlesbrough) thought the method by which the authors had approached the question of blast-furnace operation was unique in the annals of blast-furnace investigation. The usual method was to examine individual cases as thoroughly as possible and, in the light of what was known about blast-furnace reactions, draw certain conclusions. He took it the method the authors employed was what was now known as "frequency curves." In discussing such a paper it was the easiest thing in the world to make criticisms of the conclusions by citing individual very wide divergencies from the general average. The main question which should be asked was whether there were enough data to justify the drawing of frequency curves, and the application of the large-number research method. He thought the answer must be in the negative. If one considered the number of furnaces—the authors had taken something like 120—the divergencies between one group of furnaces and another, between one group of conditions and another, were very great. If one could divide the observations into smaller groups and keep to the same type of research, he thought more valuable information would be obtained than by collecting the whole 120 together.

There was no doubt that if one took 120 observations of any sort whatever and drew a graph for them, one would get some sort of curve; some of them would run about the middle, some of them to the left, and some to the right. He suggested that if the authors would, in addition, give the maxima and minima over the average curve, some rather astonishing results would be obtained, which would entirely justify splitting all the observations up into groups and dealing with them as such. The main difficulty there would probably be that the authors would have to collect a good many more figures before they could make any curve at all.

He said that as a sort of general appreciation of the method of approach adopted by the authors. He very much appreciated the attack they had made on the problem; he was sure it was one which would lead to success in the long run, though he did not think it had done so already.

In Fig. 3 the authors gave a curve for the sensible heat in the blast. There was one small point there to which he wished to refer, and which was typical. All the changes which had been made, and which were frequently referred to, were treated as if those changes had a straight-line relationship with one another. Nothing could be further from the truth than that any change in a blast-furnace, and particularly in the hearth, had any straight-line relation with any other. Those changes were followed by changes of another kind, generally obeying some sort of law of diminishing returns. If the authors would take that into consideration in drawing a curve, they would be much less liable to fall into errors in the conclusions which would be arrived at by using the final formula when applied to individual cases. The formula would be of no use if one could not apply it to an individual case for individual guidance, and, while the authors probably did not intend that should be done at the present stage, it was presumably the ultimate purpose to do so.

With regard to the values given on p. 63 for the hearth diameter, he thought he could see how those had been arrived at, and he did not very much doubt that over the whole of them the thing was arithmetically sound, although the authors did not give the method they had used. He would like to ask, however, whether the authors had taken into account the radiation losses from the hearth due to the slag, and the fact that the specific gravity of the slag, and therefore the surface exposed within the hearth, would be very much greater for each unit of weight than in the case of the iron—that is, the radiation losses allocated to slag should be, properly speaking, much greater than those allocated to the iron, because of the larger surface occupied in the hearth.

On p. 68 the authors pointed out the influence of the flow of gas through the shaft over the surface of the ore. They said: "This time of contact, assuming uniform distribution of the gas in the furnace (a condition of vital importance, which is extremely difficult to attain in practical operation), will be dependent fundamentally on the time taken by the stock to reach the hearth zone and on the mean surface area of the iron ore exposed to the action of the gas, but is only to a small extent dependent on the quantity of gas generated. If, for example, the quantity of gas be doubled the gas velocity will be doubled, and the time of contact per unit quantity of gas will be halved, the actual time of contact between gas and ore being, therefore, practically independent of the quantity of gas generated in the hearth." It appeared to him the authors overlooked the influence of the concentration. If one had an increased velocity one had also, because of

the rapid change of the reacting agents, the gas and the ore, a more rapid change of those bodies and therefore more intense action between them; the velocity of the reaction which should be allowed for in any such formula was therefore compensated for to some extent at least.

A criticism had already been made with regard to pressure-blowing, and therefore he need not say anything about that, except that he did not think the conclusion drawn in the paper would be justified.

Whatever might be thought of the individual conclusions drawn, there could be no doubt that the authors had attempted to carry out a very difficult research in an entirely new field, and they were deserving of the thanks of all for making the attempt.

Mr. E. H. LEWIS (Wishaw) said it had been his privilege to see some of the work in its initial stages, and, though the calculations were not given in the paper, he knew what a very large amount of labour had been necessary to arrive at the statistical analysis which was finally given.

The paper represented only a preliminary report. Some criticism had already been directed to the fact that 120 furnaces were not sufficient to give reliable data. That could easily be remedied if the blast-furnace managers would send in more results to the authors. The difficulty was to get sufficient results, and perhaps an even greater difficulty was to get results which were sufficiently reliable.

While appreciating the principle of the paper, there were one or two criticisms he wished to make. He had tested out the formula given on p. 63 on the furnaces for which he was responsible, and taking $\frac{K}{D}$ as being $\frac{500}{D}$, in seven out of 20 results his iron factor became a minus quantity, if corrected to "no silicon." That showed something wrong in his particular case, but was fairly easily explained. The furnaces he was operating were small, with practically no water-cooling, and therefore the radiation losses were very much reduced. For such furnaces—of which there were only two in the 120 dealt with by the authors—the figure of 500 was not appropriate and required modification. He would return to that point later.

Equation (5), $X = A + 0.12 \times \text{per cent. Si}$, seemed to work out very well as far as his own plant was concerned, but he wished to ask the authors what was the standard time in the furnace when they put A equal to 0.4 in equation (6)? Later, the authors discussed the variation in the iron factor due to the time that the ore was in the furnace, and in comparing one's own results with the authors' it was essential to know where that 0.4 began.

As a matter of fact, he had tried to arrive at it by applying more or less the authors' own statistical method of analysis to their paper. He divided Fig. 6 by lines through the figures 10, 15, 20, 25, and

30 hours, counted the number of spots in each interval, and took an average. The average of the furnaces on that page appeared to be about 14 hours, and from that figure he worked out the corrections for his own furnaces.

He wished to make one other minor criticism with regard to the time the ore was in the furnace, as given in Appendix II. As far as he could see each material charged into the furnace was made to stand alone, so far as volume was concerned. The figures worked out by that method appeared to be rather less than was observed by noticing when a change of burden came down to the tuyeres. He believed that was due to the fact that certain materials had fines in excess of their natural voids, while the more lumpy ores had the voids in excess of the fines. The result was that when the mixture was made in the furnace the fines from the finer ore ran down and filled in the voids in the rougher ore, so that the volume of the mixture was not the sum of the volumes of the constituent materials, as given in the paper. That did not matter very much, because the results as calculated by the authors were purely for comparative purposes, and as long as the same method was used right through, his criticism was without serious effect.

With regard to dry blast, the authors had given a curve in Fig. 8 which was rather suggestive. It showed the effect on iron factors of varying moisture in the air. It would be noticed that in the dotted curve, which was an approximation, the iron factor went up very much to the left. He could confirm that from his own experience. Last November he began to explore into the unknown region with blast containing less than 1 grain of moisture. Gayley did not manage to get as low as that in his plant. Comparatively soon he found the beginnings of the foothills shown on the left of the authors' Fig. 8. He hurriedly retired to the more plain ground round 1.25 grains and had stayed there, not caring to risk the increase in fuel and the more sulphurous iron obtained by going below 1 grain of moisture. He was inclined to think the authors' dotted curve was right and should be substituted for the straight line.

He had a similar experience about three weeks ago when the atmosphere went extraordinarily dry—down to 1.05 grains—and no arrangements had been made for admitting steam. The dry period lasted for about eight hours, starting in the afternoon, and about midnight that same night what was an excellent No. 4 iron went right over to white iron. The only explanation was that the moisture in the blast had fallen to 0.8 or 0.9 grain instead of being at 1.25 grains, where it was intended to be. That again was a confirmation of the dotted curve.

The authors had something to say about Johnson's theory as applied to dry blast. In Table III. (the fourth line, and the right-hand side) the authors gave the heat requirements of the moisture in the blast,

which appeared to be comparatively small compared to the total equivalent carbon. Deducting the radiation loss, it would be found that the small amount of heat taken out by the moisture appeared as a fairly large percentage of the equivalent carbon available for doing useful work. To that extent the authors very largely agreed with Johnson's theory.

The following was the explanation of what happened when he tried to prove out the authors' factors by applying them to his own furnaces. He had already stated that 500 was too large a value for K under the conditions of his furnaces, and the authors a few days ago asked him if he would make a rather bold experiment and run a furnace blind for some time to find out the radiation losses. He replied that in the present state of trade he could not risk such an experiment, but he had since tried to get at it in another way. He started by taking Mr. Evans' figure for his iron factor of 0.4×0.12 per cent. of the silicon. He then made corrections for the time in the furnace, which gave him a corrected iron factor. Then he worked the authors' equation backwards to find out the value of K . Out of 20 results, each representing a furnace running for a month, he got the following figures for a group of five furnaces. In spite of what Mr. Reese had said, those furnaces were blown by pressure from a common main, because with the little furnaces in Scotland it was impossible to do anything else; but the furnaces, though small, were efficient. The figures for K as worked out by his method came to 399, 304, 313, 308, and 386 respectively. That was rather interesting, because it confirmed what he had suspected for a long time, namely, that the two end furnaces did not get the full blast temperature which had been assumed in the calculations. He might mention that Mr. Evans some months ago forecasted that his K would be about 300. The five furnaces were of three different diameters, and four different shapes. Various kinds of iron were being made—special and ordinary hematite, forge, foundry, and basic, with silicons varying from 0.8 to 4.5. The fuel consumption varied from 27 to 35 cwt. of equivalent coal including 5 to 15 per cent. of coke. The only constants were blast pressure and temperature and the moisture content of the blast, which varied between 1.22 and 1.25 grains per cu. ft. In spite of all those variations, the authors' figures, when worked backwards in the way he had described, showed rather astonishingly uniform results.

Mr. Bailey had pointed out that a better method of arriving at the average "time for stock to reach tuyeres" for an iron factor of 0.4 was to draw a line parallel to the two sloping lines shown in Fig. 6 midway between them. Such a line gave $12\frac{1}{2}$ hrs. as corresponding to an iron factor of 0.4. The iron factor could then be expressed as equal to $0.4 + 0.12 \times \% \text{ Si} - 0.22 (h - 12.5)$, where h represented the hours for the stock to reach the tuyeres. K could then be calculated from the equation.

The following examples referred to No. 5 furnace :

	Jan.	Feb.	March.	April.
Silicon in iron. Per cent. .	3.26	2.29	1.71	1.26
Iron factor corrected for silicon ($0.4 + 0.12 \text{ Si}$)	0.791	0.675	0.605	0.551
Time for stock to reach tuyeres (h). Hrs.	25.6	23.8	23.9	24.3
Correction for (h) = 0.022 ($h - 12.5$)	0.288	0.249	0.251	0.260
Corrected iron factor (X) .	0.503	0.426	0.354	0.291
Iron per sq. ft. hearth area per hour (I). Lb.	71.81	77.41	77.05	75.67
XI	36.12	32.98	27.27	22.02
Slag per sq. ft. hearth area per hour (S). Lb.	27.46	34.35	32.83	34.62
$0.28 S$	7.69	9.62	9.19	9.69
Equivalent carbon per sq. ft. hearth area per hour ($C_1 +$ C_2). Lb.	79.53	75.61	69.01	66.88
$R = C_1 + C_2 - XI - 0.28 S$.	35.72	33.01	32.55	35.17
$K = R \times 9.5$	339	314	309	334

The average figures for the five furnaces—each for four months—similarly obtained were :

No. 1	.	.	.	.	.	399
„ 3	.	.	.	.	.	319
„ 4	.	.	.	.	.	328
„ 5	.	.	.	.	.	324
„ 6	.	.	.	.	.	419

He had no doubt that the authors would have a good answer to Mr. Reese, but his own experience of the application of the statistical method was that it was very helpful in showing when anything was wrong. He knew it did not take into account all the elaborate scientific theories as to what went on higher up the furnace, but as a rough-and-ready method forming a sort of standard curve with which other results could be compared it was very good indeed. To his mind, it would be of great benefit to the ordinary blast-furnace man if he would take the trouble to work out his own results in accordance with the authors' method. It would give him a proper perspective of some of the varying factors in the blast-furnace, and enable him to find the causes of many of the irregularities which everyone found in blast-furnace practice.

CORRESPONDENCE.

Mr. G. B. BUTLER (Marton, Yorks) wrote that the authors were to be congratulated for the great amount of work they had done; their operating results of more than 120 blast-furnaces, situated in all parts of the world, were of especial value to furnace operators.

With regard to the second and third statements in the summary of practical deductions relating to the effective time of contact between the reducing gases and the ore prior to reaching the hearth, the statement made by Sir Lowthian Bell in 1890 that there was a definite maximum rate of driving for any given furnace was typically borne out in Cleveland iron practice, where it was generally agreed that round about 16 hours' exposure to the gases was the economical limit, and that much faster driving than that resulted in failure to produce marketable iron. If that limit were overstepped, the loss of iron in the slag increased and the sulphur in the iron went up beyond all reasonable limits, and operators of those furnaces found it a matter of almost daily routine to have to check a furnace in order to keep "on grade."

In that connection it would be interesting to see how the large-capacity furnaces erected in 1883 by Cochrane's at Middlesbrough, of about 32,000 cu. ft. capacity with 10-ft. hearths, compared with the furnaces dealt with in the paper. The Cochrane No. 5 furnace, on Cleveland foundry iron, had, for the first seven years of its life, a coke consumption of 19.17 cwt. on a coke containing 7.85 per cent. of ash with a consumption of raw ironstone of 67.41 cwt., the blast temperature being 1471° F. and the weekly make 739 tons. In 1914 the capacity was increased to 33,000 cu. ft. and, blowing with a blast pressure $1\frac{1}{4}$ lb. higher, the weekly make was 900 tons with a coke consumption of 20.68 cwt., the ash in the coke being 11.42 per cent., the blast temperature 1386° F., the consumption of raw ironstone being 67.42 cwt., and of Swedish ore 1.99 cwt. Those furnaces produced iron of the best foundry qualities, and it was to be noted that the effective time of contact between the reducing gases and the ore was obtained through the larger capacity.

Further investigation should be conducted with regard to the influence of ore quality. That should particularly have regard to the use of ores containing an excess of lime over silica and to self-fluxing burdens. Furnaces using self-fluxing burdens appeared to do better work than furnaces on similar yields with burdens where a good deal of limestone had to be used. The introduction of limy ores to reduce the limestone consumption led to better furnace work and lower fuel consumption. That would appear to be due to the fact that the primary slag formed, being more limy, required less heat to take up its final lime requirements near the hearth than in the case where large amounts of limestone were required.

As to coke quality, there was no doubt that that was one of the most vital factors in furnace operation, and one could not emphasise too strongly the necessity for the production of the best metallurgical coke possible, by such means as the reduction of the number of coals used at the coke-ovens to the minimum, and by efficient cleaning, blending, and grinding methods—in that direction mechanical strength was not altogether the point to be aimed at; too dense a coke, being too slow burning, was not far removed from weak coke, after careful screening, rather it was better to aim at a coke moderately strong but of good combustibility. He (Mr. Butler) strongly recommended the removal of all breeze below 1-in. mesh; apart from its bad effect on fuel economy, that was the most deleterious material that could be charged into a blast-furnace, more especially so where dirty, unscreened limestone was also being used. Those two materials together were one of the most prolific causes of scaffolds to be met with in furnace operation, and, as most scaffolds on examination after blowing out were found to be composed chiefly of those two substances, the moral was obvious. He could, from his own experience, bear out the statement that the use of a better coke resulted in increase of output accompanied by reduced blast pressure.

Regularity of conditions in every direction was the ideal aim of every blast-furnace operator; but, like all ideals, it was never achieved under the conditions of works practice; he could, therefore, only aim steadily to approach the ideal as nearly as possible. That was typically exemplified in the case of the blast blown at a furnace. In that connection, although constant-volume blowing was aimed at, it must not be forgotten that the pressure at the furnace was the guide to the working of the furnace, and that the rise or fall of that pressure was the indication of what was occurring inside. Again, at times, it was absolutely necessary to reduce that pressure and at the same time the volume. To blow at constant pressure did not strike one as being good practice; any lowering of the resistance in the furnace would call for increased engine speed, leaving the control of the furnace too much in the hands of the engine-driver instead of the operator, and might easily result in over-driving the furnace. The statement that, with constant volume blowing, the furnace manager would take advantage of reduced pressure to increase his burden was open to serious criticism. In those matters one must step very warily; in that case the danger of over-burdening must be seriously considered, and increase of burden might easily do more harm than good.

There was no doubt that a lot could be done to obtain better furnace working, increase outputs, and reduce fuel consumption by suitable preparation of the raw materials before they were charged into the furnace. The efficient screening and crushing of limestone, the sizing of coke and its efficient screening to remove all below 1 in., provided the coke was not made too small (owing to solution loss effects), the sizing of ores, the crushing of large lumps, the removal of fines and

sintering of those up to about 30 per cent. of the burden, were all steps in the right direction, being approaches, as far as the charge of the furnace was concerned, to the ideal aim—that is, that the raw materials should all be of the same size. Such preparations were bound to produce a more physically open burden, resulting in improved furnace work and the ability to blow increased volumes of blast with lower blast pressures. That was borne out by the results obtained by operators in this country who had made progress on those lines, and recent results in Germany, where furnaces were to be found producing up to 30,000 tons per month with blast volumes of 70,000 cu. ft. per minute on blast pressures 4 to 5 lb. lower than was the rule in the United States, showed the immense value of the careful preparation of the raw materials composing the charge. In that connection it should be borne in mind that the lower the pressure at which a furnace could be economically worked the better, and the correct step to achieve that would appear to be to follow out the best features of German practice with regard to the preparation of the raw materials; the outputs of our furnaces would then go up, with reduced fuel consumptions on lower blast pressures and with increased blast volume, giving much better and more uniform furnace operation with less internal troubles.

With regard to the limit of the effective hearth diameter, it would appear, in the light of recent results obtained in Germany taken into consideration with the results obtained in the States on their large hearth furnaces of 20-ft. diameter and over, that Johnson was not far wrong in his statement that a consumption of about 250 lb. of coke per sq. ft. of hearth area per hour was the maximum consistent with good work. Consideration of the various results led one to the conclusion that that maximum diameter was reached somewhere about 16 or 17 ft., and that over that figure fuel economy was rather liable to be at a discount.

Valuable as the published data given in the paper of the various furnaces were, he would suggest that they would be even more valuable to operators if the coke consumptions were also stated in lb. burned per sq. ft. of hearth area per hour, and also if in each case the sulphur contents of the coke and slag were stated. Sulphur was the chief enemy of the furnace operator, and the content of that in the slag, owing to its effect on the fluidity and hence on the working of the furnace, was of vital importance.

Dr. C. C. FURNAS (U.S. Bureau of Mines) wrote: I consider this paper a very important contribution to the organisation of existing knowledge of a very complex mechanism, and believe that the authors should be highly congratulated. A rational and effective method of attack has been employed throughout, and the paper is valuable, further, in that it points out items most in need of study in order to get a quantitative understanding of blast-furnace phenomena.

Although the authors have called attention to the importance of

increasing the effective time of contact between gas and ore (summary and p. 71), it might have been well to emphasise this point more strongly as it is an item not usually considered in blast-furnace discussions.

In reference to particular points:

(1) There seem to be some inconsistencies in the explanation of the "iron factor." On p. 88 reference is made to the "iron factor (X)," thus definitely fixing the iron factor as the X of equation 2 (p. 60). The definition of X on that page is "the heat requirements per lb. of iron made." From the structure of the equation, I conclude that this item must include all the items going into iron itself—that is, *all* of the carbon necessary to reduce the iron from the oxide and subsequently to melt it. Yet on p. 82 I find the following:

"*The Iron Factor.*—This consists of:

- "(1) the equivalent carbon to bring the reduced iron entering the hearth zone to free-running temperature, and
- "(2) thermal requirements of hearth reduction, as previously explained."

Obviously the above does not allow for the inclusion of the carbon required for the reduction above the hearth zone, yet from the definition of terms used in the equation these must be included. Probably the inconsistency is only apparent and could easily be cleared up.

(2) One item which often limits the possible rate of driving of a furnace is the settling of the stock. Fine ores cause high back-pressures, and fast blowing often causes considerable difficulty with hanging in the furnace. This item is sometimes a limiting factor for the rate of operation, but I do not believe it was mentioned in the discussion.

(3) One wonders if closer correlation of data might not be obtainable by considering other factors than silicon in the changing iron factor. For instance, in low-sulphur, high-silicon practice, is the average hearth temperature higher? Undoubtedly the data are too incomplete to allow detailed considerations.

(4) The authors discuss the optimum rate of driving, but give no quantitative estimates of this optimum rate. It would be very interesting to see curves correlating overall efficiency with rates of driving for a typical furnace or for a number of different types of operation.

(5) In place of Johnson's equation,

$$P_1^2 - P_2^2 = K \frac{W^2}{D^4} H,$$

may I suggest the general and more exact equation,

$$P_1 - P_2 = a\sqrt{fZ \cdot dh + b},$$

where a and b are constants, and h is the height of stock column. Z is the differential rate of pressure drop at different points in the column. Its value depends on some nine different independent variables. Means of evaluating it have recently been worked out in the Bureau of Mines, and the work will be published soon.

The equation, as given, is perfectly general and involves no assumptions whatever concerning the character of flow.

(6) The statement (p. 72), "With constant-volume blowing, the furnace manager would take advantage of the reduced pressure by increasing his burden, with a consequent increased output, and reduced fuel per ton of product," is hardly clear. I cannot see why, because the pressure was reduced, the heat requirements of the furnace would go down so that the proportion of ore to coke could be increased. Is there any direct connection between these two items?

(7) The dotted curve of Fig. 8 is very interesting. A study of the optimum amount of moisture for most efficient reduction should be very fruitful.

Mr. R. C. HARDING (Stoke-on-Trent) wrote: The whole foundation of the authors' paper seems to be equation (4) on p. 63, the values given to the various factors on the right-hand side of the expression representing an average of the results from about 120 furnaces.

The authors state that the order of accuracy of these estimated factors may be gathered from the fact that, in 80 per cent. of the cases examined, coke consumptions calculated from the equation come within ± 10 per cent. of the actual amounts used in practical operation. Presumably, these 80 per cent. are furnaces which were already included in the 120 used to determine the equation in the first place, as there are only 123 furnaces given altogether in Appendix III.

To deduce an equation from the average of 120 furnaces, and then claim a reasonable degree of accuracy for it, because it gives results within ± 10 per cent. in the case of 80 per cent. of the instances from which it was deduced, would appear to be arguing in a circle, and the writer is inclined to think that the authors have been misled from this point onwards. The authors' equation eliminates any difference between the various furnaces due to:

- (a) Differences in hearth diameter.
- (b) Differences in percentage of fixed carbon in the coke.
- (c) Differences in rate of driving.

The writer would point out that it is perfectly possible to correlate blast-furnace data within the above degree of accuracy, neglecting the effect of (a), (b), and (c) altogether. Taking the furnace records which the authors give at the end of their paper, if the self-fluxing burdens

(ore and limestone in cwt. per 20 cwt. of coke) are plotted against the percentage of metallic iron in the self-fluxing burdens, a series of points are obtained, across which a band may be drawn representing ± 10 per cent., which will include 80 per cent. of the cases.

It is obvious that on such a chart no correction has been made for differences in hearth diameter, variations in fixed carbon in the coke, rate of driving, quality of iron produced, or any other variable, except the amount of slag. It is also equally obvious that closer correlation might be obtained by including the amount of coke ash with the ore and limestone and calculating the self-fluxing burden per 20 cwt. of fixed carbon in the coke.

The point, however, to which the writer specially wishes to draw attention, is that the fact of being able to correlate data from a number of different blast-furnaces on a chart of itself proves nothing at all, and if an equation be deduced from such a chart the only test to which it can be brought is whether or not it explains the effect produced by an alteration of conditions on an individual furnace. For example, take the case of furnace No. 1 in Appendix III. Applying the data given on p. 96 to equation (4), the equation shows that if the blast temperature were reduced from 1075° F. to, say, 800° F., the output of the furnace being maintained as before (a perfectly possible assumption as the furnace is only being lightly driven), the increase in the coke consumption would only be about 10 per cent.; all practical experience (confirmed by Johnson's theories) indicates that such an alteration of blast temperature, other conditions remaining as before, would require an increase in coke of the order of 20 to 25 per cent. to meet it and maintain the grade of iron that the furnace was producing.

Followed to its logical conclusion, the authors' equation would have one believe that this particular furnace would run on cold blast with no greater increase in coke consumption than about 35 per cent. The circular method of argument by which the authors have tested their fundamental equation has allowed the old fallacy, which has figured in so many heat balance-sheets, to creep in again undetected, namely, that a unit of heat brought in by the blast is of no greater value than a unit of heat generated by combustion of the coke. Far from the authors offering an "adequate explanation of a quantitative character of the results of hot blast," as they claim on p. 81, the writer maintains that they have not touched the fringe of the problem, and would ask them how they reconcile the left-hand side of their equation with the facts recorded by Sir Lowthian Bell (p. 81, "Principles of the Manufacture of Iron and Steel"), who, after careful investigation of the effect of hot blast at the Clyde Ironworks and making all possible deductions from the original saving claimed, said: "Still it was not to be denied that a saving of 20 cwt. of coke by injecting an amount of heat, contained in the blast, represented by the entire quantity capable of being developed out of 2 or 3 cwt. of coal was

sufficiently astounding." Again, on p. 256, Sir Lowthian admits that under certain conditions a unit of heat brought in by the blast is equivalent to 2.22 units of heat generated by combustion of the coke.

Sir Lowthian certainly maintained that a unit of heat brought in by the blast should not be of more value than a unit of heat generated by combustion of the coke *when properly burnt*. Whether it was possible or not under ordinary blast-furnace conditions to burn coke properly without heated blast, was a question which apparently Sir Lowthian left unanswered.

The writer would also refer the authors to Dr. Percy's book "Iron and Steel," published 64 years ago, where on p. 425 he says: "Now, as under both conditions the fuel is wholly consumed, and as the gas also which escapes from the furnace mouth has substantially the same composition, it follows that the *amount* of heat generated in a furnace working with cold blast is enormously greater for a given weight of pig iron than one working with hot blast. . . . It is therefore plain that mere quantity of heat, *i.e.* the number of units of heat evolved, can have little to do with the matter. This being admitted, the inevitable conclusion is that *calorific intensity* must be concerned." (The italics are Dr. Percy's, not the writer's.)

Again, on p. 427, Dr. Percy says: "But supposing that oxygen when heated combines with incandescent carbon more rapidly than when cold; or in other words, that combustion is more quickly effected by hot blast than cold blast; then, it is evident that there must be a proportionate increase of temperature, for, *cæteris paribus*, temperature will be in the direct ratio of rapidity of combustion. Now, observation seems clearly to have established the correctness of the supposition in question." These pages in Dr. Percy's classic (pp. 425 to 428) show how closely he was hovering on the verge of the discovery so brilliantly set out by Johnson more than half a century later.

In the writer's opinion the left-hand side of the authors' equation cannot be regarded as more than a mathematical expression of the general opinion prevalent 100 years ago, when Neilson brought out his patent, which regarded it as impossible that a weight of raw coal burnt outside the blast-furnace could displace a greater weight of coke burnt inside the furnace.

Turning to the right-hand side of the equation, it is unfortunate that the authors' expression involves the weight of slag produced per ton of pig iron. This figure is one which is determined at comparatively few works with any reasonable degree of accuracy, and it is obvious that any error will affect the "iron factor" to a material extent. To illustrate this point, two extreme cases may be taken from the authors' chart on p. 70, furnaces 5 and 69. In each case the time during which the stock is in the furnace is about the same, but in the case of No. 5 furnace the iron factor is about 0.29, while in the case of No. 69 furnace it is about 0.69, both factors being corrected to zero silicon content.

In the tables of furnace records at the end of the paper, the following particulars are given :

	<i>Furnace No. 5.</i>	<i>Furnace No. 69.</i>
Output per week	1775 tons	2090 tons
Height of furnace	81 ft.	57 ft.
Coke consumption per ton of output	20 cwt.	22.6 cwt.
Ore consumption per ton of output	43.5 "	47.2 "
Limestone consumption per ton of output	7.5 "	9.0 "
Blast temperature	1350° F.	1365° F.
Slag made per ton of output	17 cwt.	13.1 cwt.
Silicon in iron	1.68%	0.32%
Self-fluxing burden per 20 cwt. of coke	51.0 cwt.	50.0 cwt.
Metallic iron in self-fluxing burden	36.5%	33.1%

The furnace outputs are much the same, the blast temperatures nearly identical, the burdens carried per ton of coke very similar ; the ordinary blast-furnaceman would say that on these two furnaces the heat requirements for reduction, &c., would not differ widely. The authors, however, show that there is a very large difference indeed in the "iron factor" of the two furnaces. It is obvious what is the cause of the difference between the two points of view, namely, the slag volume. As the furnace records stand, the furnace working on the leaner ore mixture is stated to be producing iron with nearly 4 cwt. less slag per ton of output than the furnace running on the richer ore mixture, an impossible state of affairs.

Another pair of furnaces illustrating the same error are furnaces Nos. 43 and 46, the iron factor on the chart, p. 70, being about 0.62 for furnace No. 43, and about 0.24 in the case of furnace No. 46. Both furnaces are running on foundry iron, and their dimensions are very similar. The other material particulars are :

	<i>Furnace No. 43.</i>	<i>Furnace No. 46.</i>
Output per week	888 tons	650 tons
Coke consumption per ton of output	36.6 cwt.	27.7 cwt.
Ore consumption per ton of output	52.1 "	55.0 "
Limestone consumption per ton of output	8.1 "	17.0 "
Blast temperature	1100° F.	1250° F.
Slag made per ton of output	20.0 cwt.	21.0 cwt.
Self-fluxing burden per 20 cwt. of coke	32.9 cwt.	52.0 "
Metallic iron in self-fluxing burden	30.8%	25.9%
$\text{CaO} + \text{MgO}$ in the slag	1.76	1.38
SiO_2		

It is obvious that here again there is an error in the slag volume, furnace No. 46 being stated to be producing iron with only 1 cwt. more slag per ton of output than furnace No. 43, although consuming 12 cwt. more ore and limestone per ton of product.

This pair of furnaces also illustrates another source of error on the right-hand side of the authors' equation. They have assumed a constant "slag factor." The writer is of the opinion that few furnacemen would agree that this could be anywhere approaching accuracy in the case of these two furnaces, both making foundry iron, the basicity

of the slag from No. 43 furnace being totally abnormal for a furnace running on this grade. It is a safe statement to make, that if furnace No. 43 were given the same blast temperature as No. 46 and the basicity of the slag reduced to the same figure, the coke consumption in No. 43 would be no greater than that of No. 46; and yet, according to the authors, the main difference between the two furnaces is in the "iron factor." In view, however, of the exception taken to the left-hand side of the authors' equation, it is perhaps labouring the point unnecessarily to draw fine distinctions between the "iron factor" and the "slag factor," more especially as the authors themselves on p. 88 seem to regard their "iron factor" as sufficiently elastic to include, not only the "temperament" of the furnace, but the temperament of the blast-furnace manager as well.

The authors state (p. 88) that "The mathematical expression ultimately developed agrees qualitatively with customary blast-furnace experience, and offers the advantage that it links up the functions of the hearth and shaft in one general equation." The writer contends that the authors' mathematical expression is totally at variance with customary blast-furnace experience, and, like all other attempts to regard the functions of the hearth and shaft together, it fails absolutely to offer an adequate explanation of the facts.

In the writer's opinion the last word still lies with Johnson, who, at the end of his chapter on Mechanical Principles of the Blast-Furnace (p. 138), said: "It is a safe statement that if one-half the scientific research had been expended on these practical mechanical questions that has been spent on chemical equilibria and lop-sided heat balances, the science and art of furnace operation would be far ahead of where they are to-day."

Dr. H. J. BUSH (London) wrote: In their admirable paper Messrs. Evans and Bailey state that "Any method available for improving the uniformity of distribution of the reducing gas would essentially have the effect of increasing the time of contact of the gas and ore, and would therefore result in a reduced iron factor." In confirmation of this, they mention the beneficial effect of using coke that has been deprived of breeze by screening and of suitably preparing the physical nature of the ore in the burden by agglomerating the fines. This latter factor has long been recognised and duly appreciated by Continental iron-masters, as may be gathered from the large number of sintering plants installed and at present under construction. Straight-line Dwight-Lloyd machines are now building that will treat 800 tons of fine ore in 24 hrs.

It is rather interesting, in this connection, to recall the opinion expressed some years ago as a result of practical large-scale tests by a late general manager of the "Bochumer Verein." In order to arrive at a definite conclusion on the value of using agglomerated fine ore, a quantity of about 10,000 tons of ore was sintered on a straight-line Dwight-Lloyd machine, and a furnace set apart for determining the

effect of adding varying proportions of the agglomerate to the burden. The percentage added was varied from 20 to 90 per cent. Though actual figures were not disclosed, for fear that it might prejudice the price at which fine ores could then be bought, the considered opinion was privately given that even if lumps and fines could be purchased at the same price it would still be preferable to buy the latter and agglomerate them, as the agglomerated ore gave a much steadier running furnace and showed an appreciable saving in coke.

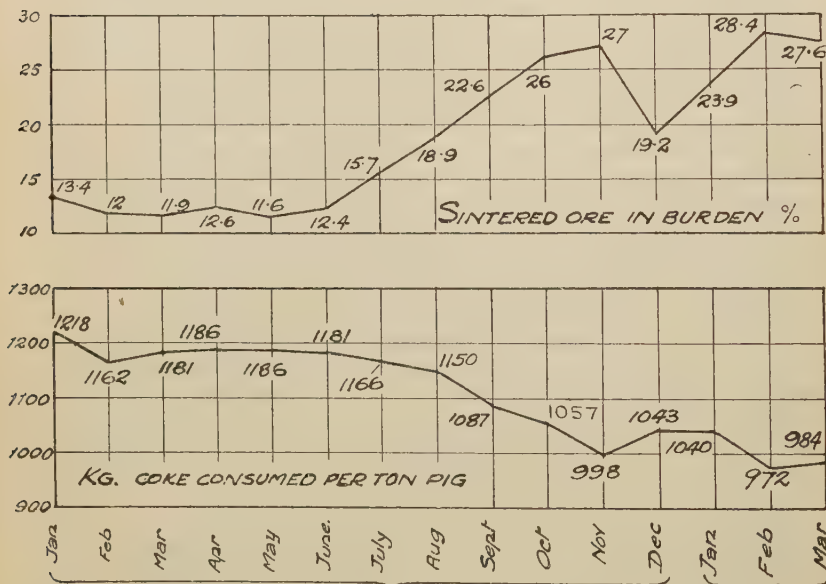


FIG. A.

(Reproduced by permission of *Stahl und Eisen*.)

It has since been confirmed from other sources that a furnace supplied with agglomerate instead of fine ore is more uniform in operation and shows no tendency to "slip."

The saving in coke resulting from the use of sintered ore is shown very clearly in the accompanying graph, Fig. A.

By raising the percentage of agglomerated fines in the burden from 13.4 to 28.4 per cent., the coke consumed per ton of pig iron was reduced from 1218 to 972 kg.—that is, a saving was effected of over 4 cwt. of coke per ton of iron.

It should in fairness be stated, however, that part of the saving in this case is due to there being a certain amount of spathic ore in the charge, which is decomposed during the sintering process.

At an American works a test carried out over a period of twelve days showed that by mixing only 10·5 per cent. of sinter with the burden :

the production was increased from 566 to 579 tons ;
the coke per ton of iron was reduced from 2043 to 1979 lb. ;
the blast pressure was decreased from 16 to 14·8 lb.

The Chateaugay Ore and Iron Co., of Lyon Mountain, N.Y., use only sintered material, and the American Sintering Co., of Hubbard, Ohio, are said to carry on a remunerative business of custom sintering of fine ores.

To sum up, the experience of the last ten years justifies the conclusion that the use of sintered material in the blast-furnace generally brings about a higher output and a reduced coke consumption, and thus forms a ready means of lowering the "iron factor," one of the main items determining the total thermal requirements of the furnace, as pointed out by the authors.

Mr. T. L. JOSEPH (U.S. Bureau of Mines) wrote : During the past year the writer has periodically exchanged ideas on blast-furnace topics with the authors of this paper. This correspondence has been helpful and stimulating. Time will not permit of a detailed discussion such as this paper deserves, but I do want to take this opportunity to endorse the main features of this paper, and particularly the authors' statement that a correlation of a large number of blast-furnace data indicates features of practice which offer the greatest opportunity for closer study and improvement.

Due to the fact that in the blast-furnace large volumes of gases move counter-current to the descending stock, absolute size and uniformity of particle size of ore and coke are of outstanding importance. As the disparity in particle size of ore and coke increases, the big bell clearance, the size of the charges, the sequence of depositing ore, coke, and stone on the big bell and, in fact, stock distribution in general, become more difficult and important, as these factors largely control the amount of contact between the gas and ore and the extent of the preparation of the materials in the shaft.

In a report* published in 1924 the writer called attention to the suggestion of Van Vloten,† that the descent of coke in the bosh is not in vertical lines, but that the flow is analogous to the motion of a liquid through a funnel, it being supposed that a funnel is mounted over each tuyere. Due to the fact that the stock does not descend at a uniform rate in all parts of the furnace, the problem of getting uniform gas distribution is all the more important. Stream-lines of stock descent

* "Effect of Coke Combustibility on Stock Descent in Blast-Furnaces," *Transactions of the American Institute of Mining and Metallurgical Engineers*, 1924, vol. lxx. pp. 224-233.

† *Stahl und Eisen*, 1893, vol. xiii. pp. 26-30.

are set up due to localised combustion at the tuyeres, thus preventing a full realisation of the counter-current principle, even though the gas is distributed uniformly. Burden changes are often manifested in the composition of the slag and metal in a comparatively short time, due to the faster descent of the stock along the periphery of the furnace. It appears that it is a simpler matter to approach a perfect counter-current effect through improved physical structure of the ore and coke rather than through changes in the flow of the stock, which would probably necessitate furnaces of oval rather than circular shape.

In regard to the estimation of time required for stock to reach the tuyere zone, it seems that the faster travel in parts of the furnace must be taken into consideration. The method used for computing the time of stock in the furnace as reported in Appendix II. gives relative average values, but it seems that in practice the time of stock travel in the zone of fastest movement might be the controlling factor.

Mr. P. LIST (Barrow-in-Furness) wrote: The authors deserve our best thanks for their paper, if only on account of the amazing industry shown in compiling Appendix III. Whether the formulæ established by them have any practical value, only application to concrete cases can show.

The paper is not free from blemish. Some of the hard things said about it at the meeting, though perhaps not wholly deserved, could not be called entirely unjust. In the first place, as one of the critics remarked, the authors should have worked out their coefficients by districts operating under the same conditions. Instead of one formula, it is true, they would have had as many as there are groups of furnaces, but it would have made it easier for us, the practical men, to apply the formula to our respective furnaces.

In the second place, it would have been advisable to give in detail the process by which Howland arrived at his empirical formula. We would then have known, what we now can only guess, that the percentages of the different gases which enter the formula are given by volume and not by weight.

These criticisms, however, are only by the way. If comparison be made between the main formula developed by the authors on p. 63, and that of Howland as shown in Appendix I., it will be found that they give about the same results. Applied, for instance, to furnace No. 13 in Appendix III., Howland's formula gives 1422 lb. for the carbon burnt at the tuyeres, and that of the authors 1437 lb., the difference being slightly over 1 per cent. Both formulæ may of course be wrong, but it is at least strange that, although wrong, they give similar results.

Another test of the authors' formula is the following. It is well known that the higher the silicon in pig iron, the higher the coke consumption. It has been found in actual practice that above a certain percentage of silicon the fuel consumption increases rapidly and quite out of proportion to the actual percentage of that element.

The authors' formula confirms this. Again, taking No. 13 furnace and making allowance for the decrease in output, adjusting further the iron factor for 4 per cent. of silicon, it will be found that the coke consumption increases by 539 lb., which is not very far from what has been found in actual practice.

Evidently some practical use can be made of the formula in its present form. If the authors succeed in making it more accurate still, as they hope to do, blast-furnacemen can only rejoice.

The AUTHORS, in reply, desired to express their appreciation of the interest taken in the paper, and particularly of the reasoned criticism to which it had been subjected.

Deductions based upon a statistical investigation of operating data needed to be checked from the outset with the results of practical experience, and if they did not agree, either the method of examination was proceeding on incorrect lines or other factors were involved whose influence needed to be further determined. In that respect the authors gratefully acknowledged the assistance received before and after the presentation of the paper from authorities whose criticism had been particularly helpful in indicating lines of investigation into the effect and value of factors not yet examined in detail.

Mr. Reese's criticism that the method adopted in arriving at the factors submitted in equation (4) was not developed in detail in the paper could only be replied to by stating that it was purely empirical, based upon methods of trial and error and developed as logically as possible until factors were obtained which were in general agreement with operating results. Some assistance was obtained from the work of J. E. Johnson and Richards, as stated on pp. 81-83. The relative order of the factors for R , X , and Y agreed with the order as set out by Johnson. The method used for their final valuation, however, would require a long and laborious explanation, which would add considerably to the length of the paper without adding to its value.

The reasons for the adoption as a first approximation of a constant figure of 350 lb. of carbon used other than at the tuyeres were set out in Appendix I. That was, therefore, not an assumption but a figure arrived at from existing statistical evidence. The same applied to the other so-called assumptions, which for the most part were based on results available.

The point made by Mr. Reese, Dr. Furnas, and Mr. Butler relative to an alteration of burden as the result of a drop in pressure with constant volume blowing indicated the difficulty of expressing in a simple manner the results of a general observation without taking all the factors into consideration. To some extent the difficulty arose out of the necessity for differentiating between the results of a continued decrease in blast pressure due, for example, to improvement in coke quality and a temporary drop due to one or other of the complex factors existing in blast-furnace operation. The question was now under

investigation, and it was hoped to submit practical results at a later date.

The authors did not agree with the suggestion made by Messrs. Reese, Sillars, and others that more progress would have been made at the outset by taking groups of furnaces having factors in common, than by averaging results of widely varying conditions of practice. General factors common to all furnaces could only be ascertained from a general study of all furnaces, factors common to a single group being subsequently investigated in detail. Possibilities in that direction were shown in Fig. 7, where divergence from the average of a large group of furnaces with a factor in common—ore quality—was indicated. Further, unpublished work by Mr. E. H. Lewis showed that, after adjustments of the general factors had been made to meet local conditions, the method could be used to study systematically the operation both of individual furnaces and of groups of furnaces with common factors. The statistical method adopted in fact necessitated argument from the general to the particular rather than *vice versa*.

Mr. Sillars was quite correct in stating that criticism of the paper was easy by "citing individual very wide divergencies from the average." A study of extreme cases, however, frequently helped in bringing to notice factors which were difficult to identify in average results, and as information grew and further results accumulated those factors could be investigated. Whilst some progress was being made in that direction the authors considered that evidence was only sufficient as yet to allow of the broadest deduction being made, and much more data was required before finality could be reached as to the precise value of the various factors that existed.

It was quite true also that the factors examined by themselves had a straight-line relationship, but when examined as a whole, one factor operating concomitantly with another opposing one, there was obviously a law of diminishing returns. One example was the reduction of fuel consumption by an increase in output opposed by the increase in fuel by consequent reduced time of contact. Another case of a different type was shown by the blast temperature curve, Fig. 1, where the effect of an increase of temperature was given as a function of the carbon consumed at the tuyeres. As that was reduced with increasing blast temperature, it was obvious that successive increments of temperature would have a diminishing effect on the total fuel consumed. By plotting sensible heat in the blast against carbon consumed at the tuyeres the relationship was a straight line one, whereas if plotted against the total fuel consumption, say, per ton of pig iron, it was probably hyperbolic in type.

In the radiation factor the authors had attempted to group all the sources of radiation, including radiation for slag and iron and external cooling loss specified in greater detail on p. 81. The radiation factor would have to be modified to some extent by the character and extent of water or air cooling adopted, and in small air-cooled furnaces, that,

as was shown in Mr. Lewis' contribution, would have to be considered with reference to the extent of exposure to the prevailing winds.

The point raised by Mr. Sillars regarding the influence of gas velocity on the reduction velocity was a most interesting one. In many chemical reactions the presence of a comparatively inert film on the surface of a solid acted on by a gas played a considerable part in reducing the velocity of reaction. Work in progress by Professor Bone and his collaborators promised to throw some light on that, but the authors had not, on the evidence as yet available, been able to determine whether that factor played an important part.

Mr. Lewis had been good enough to meet his own criticism of the paper, and the authors did not feel that they could improve on Mr. Lewis' own analysis.

The method of estimating time in the furnaces adopted by the authors was open to the objection raised by Mr. Lewis and also by Mr. Joseph. It simply gave average values and did not take into consideration the faster descent of some of the constituents in the shaft, due either to difference in size or to the distance from the wall of the furnace. It was difficult, however, to see how that could be allowed for, and for the time being the authors had to be content with an average value, to be adjusted possibly as more detailed and accurate information became available.

The authors desired to acknowledge the constant and continued assistance that Mr. Lewis had given throughout the investigation. Mr. Lewis was applying to his own furnaces, in a monthly analysis, the method advocated by the authors. Some of the results had been given by him in his contribution to the discussion, and the authors were eagerly looking forward to a comprehensive paper by him on the results obtained at Wishaw, where, owing to the introduction of dry blast, a variable which could not be investigated in a general survey was eliminated, and where, consequently, factors normally masked would be more clearly indicated.

Mr. Butler's practical contribution to the discussion was of considerable interest. Sufficient details of the operation of the Cochrane furnaces to allow of accurate analysis were, unfortunately, not given, but it was interesting to note that the conclusions arrived at by the authorities mentioned by Mr. Butler regarding the influence of time of contact supported many of the contentions put forward by the late Mr. C. Cochrane in his famous controversy with Sir Lowthian Bell.

There was no doubt as to the need of investigation of ore quality, and as the research by Professor Bone and his collaborators progressed, it was hoped that a method of comparison would be evolved which could be taken into consideration in further developments of the statistical survey.

The coke consumption per unit of hearth area could be easily calculated from the data provided, but sulphur content in coke and slag were only given if they were available from the returns submitted.

Dr. Furnas in his keen analysis raised several points which were not expressed sufficiently clearly in the paper, and which could be briefly explained. The iron factor X consisted of the hearth heat requirements per pound of iron. As would be seen from pp. 81 and 83, all the hearth heat requirements were of the order of three to four times the actual consumptions according to the best available existing estimates. The whole of that surplus heat and reducing power was carried forward up the furnace by the gas stream, and the requirements for reduction above the hearth zone must be drawn from that common pool. The authors agreed that a closer correlation might be obtained if the hearth temperatures could be considered, but as it did not appear to be possible to correlate the latter with the quality of iron made, and as they could not obtain measurements of sufficient reliability, they were reluctantly forced to leave that consideration for the time being. It was hoped at a later date to be able to publish figures which would enable curves to be drawn showing the effect of rate of driving on over-all efficiency and a well-defined optimum. A sufficient range of variation on a single furnace was seldom obtained, but certain valuable practical data had already come to hand.

The equation replacing that of Johnson in connection with the resistance of the stock to the gas stream was an extremely valuable addition to the discussion.

The confirmation of the coke requirements for increased silicon content in the iron which was put forward by Mr. List was of considerable interest, and showed one of the essentially practical applications of the formula put forward by the authors. It was quite correct that Howland's formula was empirical, but it was based on well-known data of gas constants, for which reference must be made to Howland's paper,⁽¹⁷⁾ as it would have lengthened the paper to have inserted the reasoning in full.

The authors appreciated Mr. Joseph's contribution, and acknowledged the assistance that had constantly been given by him and his colleagues during the course of the investigation. Mr. Joseph's own work had illustrated the importance of uniformity of size of ore and coke in blast-furnace practice, and the investigations that were now in progress by the observers of the Bureau of Mines on the factors which in blast-furnace practice would influence the time of contact between ore and gas promised to be of considerable practical as well as theoretical importance.

The results quoted by Dr. Bush indicating the advantages of sintering as a method of increasing the efficiency of contact between the gas and ore were of interest.

Mr. Harding's contribution was essentially a continuation of a series of discussions which had extended practically over the period of the investigation, and which had been particularly helpful to the authors, in view of the fact that Mr. Harding had placed freely at their disposal his wide experience in blast-furnace practice. Mr. Harding was

probably correct in stating that 120 furnaces were not a sufficient sample to justify the submission of a final equation ; the authors at the moment, in fact, did not claim that the paper did more than " represent an actuarial average of *furnaces examined*, which, as results accumulate, is definitely open to modification and development." The equations

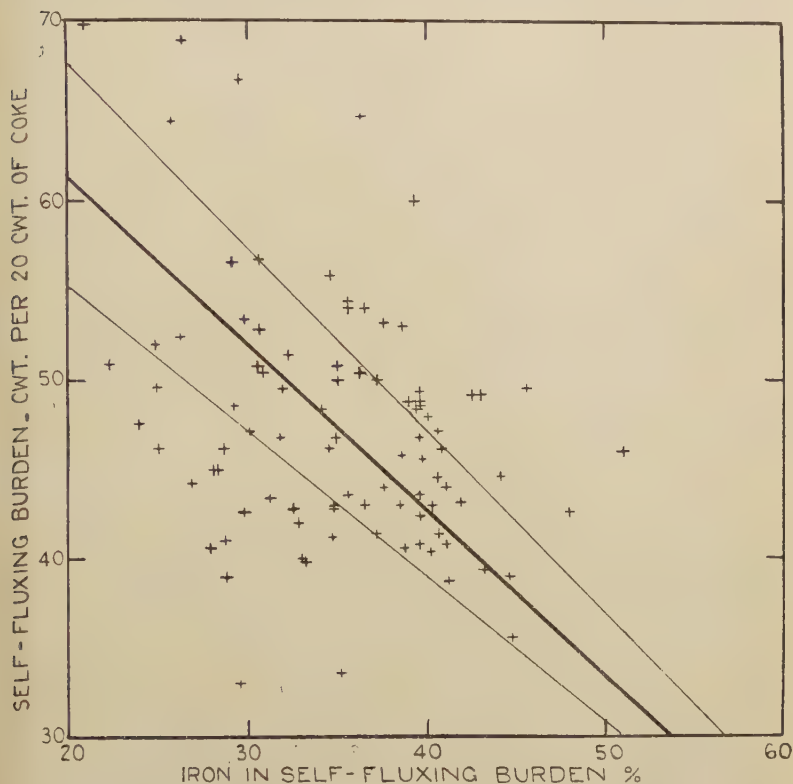


FIG. B.—The Relation between Self-Fluxing Burden, Coke and Iron Content (47% within $\pm 10\%$ of the mean).

submitted, however, represented the most effective correlation that the authors had yet been able to develop. They had tried other methods. Mr. Harding's suggestion, for example, of eliminating the influence of hearth diameter, fixed carbon in coke and rate of driving, and plotting the self-fluxing burdens of the furnaces examined against the percentage of iron in the burden, had given the results submitted in the above graph, Fig. B. Instead of 80 per cent. of the cases coming within ± 10 per cent. of the mean, as Mr. Harding suggested, the actual percentages within those limits was of the order of 47, leaving 53 per cent.

outside, whilst the extreme limits were ± 30 per cent. on either side of the mean. It was obvious that the correlation was not nearly as close as that submitted in the paper.

Mr. Harding questioned the value of the equation in explaining the effect produced by an alteration of conditions on an individual furnace, and instanced, as an example, the effect of blast temperature. That was fundamental in its importance. If the method of correlation developed did not eventually explain quantitatively the effect of blast temperature, it was useless as a practical basis of comparison of blast-furnace practice. Mr. Harding stated that "applying the data given on p. 96 to equation (4), the equation shows that if the blast temperature were reduced from 1075° F. to, say, 800° F., the output of the furnace being maintained as before (a perfectly possible assumption as the furnace is only being lightly driven), the increase in the coke consumption would only be about 10 per cent. ; all practical experience (confirmed by Johnson's theories) indicates that such an alteration of blast temperature, other conditions remaining as before, would require an increase in coke of the order of 20 to 25 per cent. to meet it and maintain the grade of iron that the furnace was producing."

Actual alteration of blast temperature would alter—

- (1) the heat available at the tuyeres,
- (2) the slag volume from the coke ash,
- (3) to some extent the time of contact, owing to a change in the relative volumes of coke and ore in the furnace.

The authors would not, at the present stage of the investigation, eliminate also the possibility of other secondary effects—due to an alteration, for example, in the rate of combustion of the carbon at the tuyeres and the rate of reduction of the ore in the shaft—which might have an important bearing upon the total fuel consumption in the furnace, but which in themselves could not be credited in a thermal equation directly to sensible heat in the blast. Those secondary effects must be credited to the various factors which they influenced. If the authors could obtain fully detailed information of an increase in the coke consumption of 25 per cent. under the conditions specified by Mr. Harding, it would materially assist in the evaluation of those various secondary effects which might be produced.

Mr. Harding quoted Sir Lowthian Bell's figure of 20 cwt. of coke saved at the Clyde Ironworks with hot as compared with cold blast, but omitted to mention that on the same page* he pointed out that "while 20 cwt. of coke per ton of iron were saved in Scotland, only 13 cwt. of coke per ton of iron were saved in Wales. Either of these quantities justified its introduction into France, which laboured under the disadvantage of dear fuel ; but great must have been the surprise

* Sir Lowthian Bell, "Principles of the Manufacture of Iron and Steel," p. 81.

of the owners of the Torteron works in that country when they found their saving was only 6 cwt., or about half of the lesser quantity just named." Discussion as to the effect of hot blast, therefore, was useless without a knowledge of all the factors involved, and any information which Mr. Harding could give in that direction would be greatly appreciated.

The authors would not like, at the present stage, to disregard the possible influence of "calorific intensity" on furnace economy, but that was a matter for further investigation. It should be pointed out that "calorific intensity" was a relative term, and must include the rate at which the heat was absorbed as well as the rate at which the heat was generated.

The authors were grateful to Mr. Harding for pointing out the difficulties of accurate returns of slag volume, with which they were in perfect agreement, and it was not within the power of the authors when attacking the problem by this statistical method to select their data, no matter how suspect certain of it might be, since those figures which appeared to be most widely divergent had been shown time and again to be the clue to further factors at first unsuspected. Thus, although the inaccuracy in the slag figures quoted by Mr. Harding would account for a proportion of the divergencies in the cases which he quoted, it was preferable to withhold judgment until those figures could be brought into line with the general scheme, or with some definite group.

The probable effect of basicity of slags had previously been raised by Mr. Harding, and the authors undertook an attempted correlation of that factor with fuel consumption and all the other variables which it could be reasonably assumed to affect. In no case could any relationship be established, and that would lead to the assumption that the basicity of the slags, as determined from the slag analysis normally returned, was a misleading figure, or that the basicity had less influence than was customarily considered to be the case.

With respect to the constancy of the slag factor, there was need for a pyrometric investigation into the running temperatures of British slags on the lines of that carried out by the U.S. Bureau of Mines. It might be that temperature differences would be revealed by such an investigation, but the correction that would ultimately be required in the slag factor already submitted would probably be only of a small order.

There was one other point that Mr. Harding made with reference to the method of correlation suggested by the authors when he stated that "like all other attempts to regard functions of the hearth and shaft together, it fails to offer an adequate explanation of the facts." The authors must refer Mr. Harding to Johnson,* and to the concluding statement that "Here is a confirmation of the twofold thermal balance of the furnace . . . also that the two quantities bear a definite ratio to each other, depending upon the conditions of the operation."

* *Loc. cit.*, pp. 70-74.

The authors desired to emphasise the necessity at the present stage of the investigation of securing the fullest possible data of furnace operation, whether it supported or negatived the conclusions put forward, as it was only by examination of such data that further progress could be made. In that connection, the recent publication by blast-furnace authorities of results at their works had been of considerable service, and if details of varying practice in different producing districts could be published it would assist in the solution of many of the problems, theoretical and practical, of modern blast-furnace technology.

THE REACTIVITY OF COKE.¹

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INTRODUCTION.

THE properties of coke are being investigated from a number of aspects at the Fuel Research Station, Greenwich, and one programme of research has led to the evolution of an empirical method for the determination of the "reactivity" of coke towards carbon dioxide. Apart from the more fundamental work of investigating the mechanism of the reaction, a large number of cokes supplied by the National Federation of Iron and Steel Manufacturers have been examined. The present paper is intended to show the differences which exist between such cokes, and is offered as a progress report. Work on the explanation of the reaction phenomena is proceeding, and will be included in a further paper when the data are more complete.

The proposed method for the determination of reactivity values has been described in a Fuel Research Board Technical Paper,² and the present paper contains only the essential features.

The reactivity of coke may be defined as a measure of the velocity of reaction between coke and carbon dioxide, the term "combustibility" being reserved for the reaction between coke and oxygen. In the method adopted, "reactivity values" are measured by the volume of carbon monoxide produced when a definite volume of carbon dioxide is passed at a constant rate over a definite volume of sized coke maintained at a constant temperature. Conditions have been arbitrarily fixed so that the values for what may be termed "normal" high-temperature cokes lie in the sensitive portion of the scale.³

¹ Received March 5, 1928.

² J. H. Jones, J. G. King, and F. S. Sinnatt, "The Reactivity of Coke. Standardised Method for the Determination of Comparative Values," *Fuel Research Board Technical Paper*, No. 18, 1927.

³ Such a scale bears a logarithmic relationship to the actual reaction velocities, and thus, as shown on p. 147, different portions will have different sensitivities.

The conditions adopted for the method are:

Size of coke	Through 10-mesh and retained by 20-mesh I.M.M. sieve.
Length of coke measured with thermocouple in position . . .	7.5 cm.
Internal diameter of tube . . .	1.4 cm.
Temperature of coke	950° C.
Volume of carbon dioxide used for each determination	100 ml.
Rate of passage of carbon dioxide . .	5 ml. per min.

EXPERIMENTAL.

The apparatus is shown diagrammatically in Fig. 1 (Plate V.). The reaction tube is made of clear silica and is shown in detail in the smaller drawing. It is fitted with a steatite piston attached to a long silica capillary tube through which the thermocouple sheath is fixed, the whole being a sliding fit into the reaction tube, in which it is held in position by a rubber stopper (*D*). A constant volume of coke is used, and a definite procedure is adopted to ensure uniform packing. The reaction temperature is controlled by means of two platinum/platinum-rhodium thermocouples, one placed in the centre of the coke, the other recording the furnace temperature immediately outside.

The reaction tube can be connected at the inlet end with (*a*) a stream of nitrogen, or (*b*) a supply of carbon dioxide.

(*a*) The nitrogen is obtained from a cylinder and is purified by washing with alkaline pyrogallol and subsequent passage over reduced copper maintained at 600° C. by the preheater furnace (1). It is dried by sulphuric acid, calcium chloride, and phosphoric oxide, before entering the reaction tube at (14). The reservoir (2) is arranged so that the apparatus can be left under pressure of nitrogen while both furnaces are cooling.

(*b*) The carbon dioxide is prepared in a Kipp's apparatus and washed with sodium carbonate solution and concentrated sulphuric acid. It then enters the graduated gasholder (5), from which it is expelled by means of a concentrated solution of magnesium chloride which flows at a constant rate into the side tube from the Marriott bottle (6). This is fitted with a capillary air tube (7) and a calibrated jet (8), so arranged that the gas is expelled at a rate of 5 ml. per min., regulation being effected by

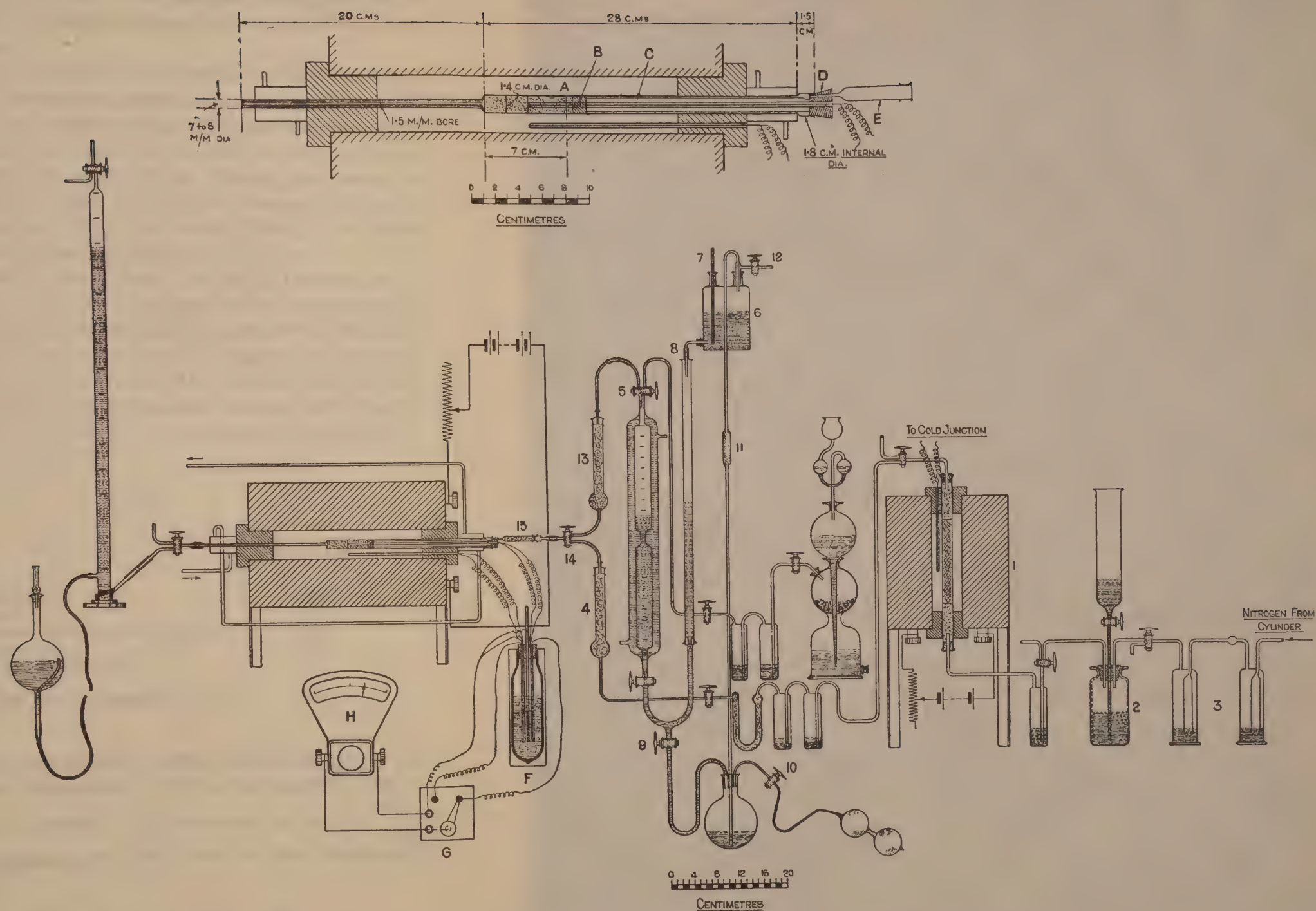


FIG. 1.—Apparatus for the Determination of the Reactivity of Coke.



variation of the head. The gasholder is graduated in two portions, each with a capacity of 100 ml. The gas after leaving the holder passes through phosphoric oxide drying tubes at (13) and (15) into the reaction tube.

The capillary of the reaction tube is connected to a three-way tap and thence to a nitrometer containing potassium hydroxide solution. In the actual determination, after pre-treatment with nitrogen, carbon dioxide is passed at the rate of 5 ml. per min., this rate being checked for each 10 ml. During the passage of the first 100 ml. the exit gases are allowed to escape to the air, and the insoluble portion from the second 100 ml. is collected in the nitrometer over potassium hydroxide solution.

Range and Sensitivity of the Method.—At 950° C. the equilibrium mixture in the system $\text{CO}_2\text{--CO--C}$ corresponds to a concentration of 98.7 per cent. of carbon monoxide—that is, under the conditions of the experiment a higher value than 197.4 cannot be obtained. Table I. shows the range covered by the method, and contains the results of a number of determinations for samples of cokes of the classes designated. These are not necessarily representative of the class to which they belong.

TABLE I.

Fuel.	Reactivity Value.
1. Maximum obtainable	197.4
2. Active charcoal	192
3. High-temperature gas coke (vertical retort)	140
4. By-product oven coke	100
5. South Wales metallurgical coke	70
6. Beehive coke	43
7. Glazed skin separated from specimen No. 6	30

The scale becomes less sensitive as the constituents of the gas approach equilibrium proportions. If R is the reactivity value, then K , the velocity constant, is proportional to $\log \frac{100}{100 - \frac{1}{2}R}$, and the following figures give some idea of the relationship between R and K :

R	10	50	100	150	190	197
K	2	12	30	60	130	182

Thirty determinations conducted to test the sensitivity and accuracy of the method showed it to be satisfactory. An investigation was also made of the effect of variation of:

- (a) Rate of passage of carbon dioxide.
- (b) Volume of coke used.
- (c) Temperature of reaction tube.
- (d) Particle size.

The results are given in detail in the Fuel Research Board Technical Paper, and show that, under the conditions of the experiment, with the apparatus as at present used, there should be no significant errors due to inaccuracies in (a), (b), or (d). On the other hand, accurate temperature control is imperative.

The reactivity values thus found, though bearing a definite relationship to the velocity of reaction, cannot be dissociated from the method of determination, and, while comparable one with another, must be considered as values measured on an arbitrary scale. The value is not constant for a given sample, but alters as the treatment with carbon dioxide is prolonged. There appear to be three distinct values for any sample of coke. These have been termed Reactivities I, II, and III.

Reactivity I (R_I).

This is the closest approximation to the initial reactivity value which it is possible to obtain by the method adopted. The coke is heated to 950° C. in one hour in a current of nitrogen maintained at the rate of 1 litre per hour. The conditions are kept constant for a further hour, after which the nitrogen stream is stopped, and 100 ml. of carbon dioxide passed at the prescribed rate before carrying out the actual determination.

Reactivity III (R_{III}).

The amount of carbon monoxide produced decreases in the early stages of passage of the carbon dioxide, and thus the value for Reactivity I is the mean over a short space of time. If the passage of carbon dioxide is continued over a more extended

period, the decrease continues until a value is reached which is approximately constant.

The effect of continued passage is illustrated in Fig. 2. Three separate determinations are shown, two interrupted and one continuous. In the interrupted determinations the coke samples were allowed to cool overnight in an atmosphere of nitrogen, while in the continuous experiment as soon as one determination had

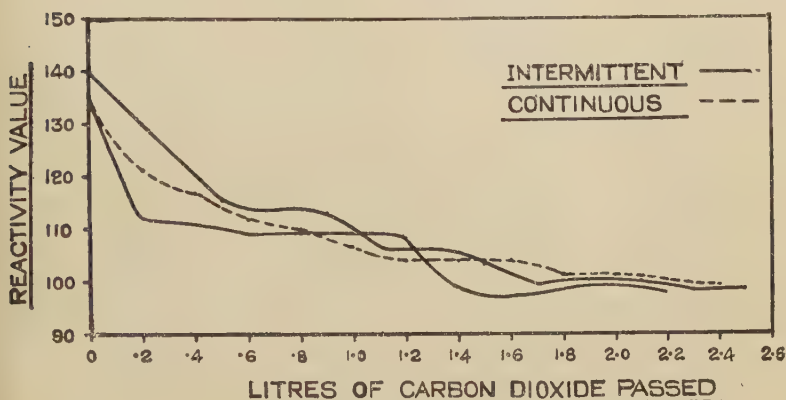


FIG. 2.—The Effect of the Continuous Passage of CO_2 .

been made a second was commenced, this process being repeated until approximate constancy was established.

Table II. contains the actual figures obtained, and indicates the degree of concordance possible in a series of repeat determinations.

With all the specimens of cokes examined, which now number over fifty, the same behaviour has been observed. In some cases the constant value is only slightly lower than R_I , while in others the difference is considerable. It will be recognised that the value designated as Reactivity III (R_{III}) is that at which several successive determinations show no appreciable decrease; later work, not yet published, has shown that this is not strictly a constant value; it can be slightly reduced by the action of carbon dioxide for long periods. This point will be elaborated at a later stage.

TABLE II.—*Experimental Determinations of Reactivity III.*

CO ₂ passed. Litres.	Interrupted Passage (A).	Interrupted Passage (B).	Continuous Passage.
0.2	140.0	135.0	134.0
0.3	...	...	...
0.4	130.0	112.0	121.5
0.5	...	...	...
0.6	...	110.0	117.0
0.7	115.0	...	...
0.8	...	109.0	112.0
0.9	113.5	...	...
1.0	...	109.0	110.0
1.1	113.0	...	...
1.2	...	108.0	107.0
1.3	106.5	...	...
1.4	...	98.0	104.5
1.5	106.0	...	...
1.6	...	97.0	104.5
1.7	103.5	...	...
1.8	...	98.5	104.0
1.9	99.5	...	...
2.0	...	99.0	100.5
2.1	100.0	...	...
2.2	...	97.0	...
2.3	100.0	...	...
2.4	...	...	100.5
2.5	98.0	...	...
2.6	...	...	100.0
2.7	98.0	...	...
2.8	...	...	98.0
Mean value	99.0	98.0	100.0

Reactivity II (R_{II}).

In cases where there is a considerable difference between R_I and R_{III} the pre-treatment with nitrogen before the determination of R_I may have an effect on the value obtained, causing a decrease, until after about 5 hours' passage at 950° C. a value is obtained which can for all practical purposes be considered constant (the value after 5 hours being equal to that after 24 hours). This value is termed Reactivity II (R_{II}).

During the period of initial heating volatile matter is removed from the coke, so that if the standard pre-treatment is not carried out the gas collected in the nitrometer contains too large a percentage of constituents other than carbon monoxide to allow its

value to be recorded without gas analysis. After 5 hours' pre-passage of nitrogen both the volume of gas collected and its carbon monoxide content are reasonably constant. After the standard pre-treatment of 1 hour, with a good metallurgical coke the carbon monoxide content is such that comparative results can be obtained without the necessity for gas analysis.

There is no simple relationship between the amount of volatile matter present in the coke and the difference between R_I and R_{III} . The effect of the passage of nitrogen does not consist entirely in the removal of volatile matter; it has some bearing on the previous heat treatment of the coke, and this question is still under investigation.

If a coke be heated in nitrogen until the R_{II} condition is obtained, and be then subjected to prolonged treatment with carbon dioxide, the value finally recorded is that of R_{III} . Thus, with all cokes so far examined R_{III} can be obtained either directly from R_I by prolonged passage of carbon dioxide or by passage of nitrogen until R_{II} is reached, followed by continued passage of carbon dioxide.

REACTIVITIES OF COMMERCIAL COKES.

It is not the authors' intention in this paper to discuss at any length the possible explanation of the effect of continued passage of carbon dioxide or nitrogen, but rather to present the results obtained with a number of cokes examined in co-operation with the Northern and Midland Coke Research Committees.

The values obtained are given in Table III. Nos. 1 to 27 are metallurgical cokes, the others being added for the purpose of comparison. The whole of the useful portion of the scale which has been adopted is covered by metallurgical samples actually in use at the present time. It will be observed that wide differences in reactivity exist between these, Nos. 1 to 15 being quite distinct from Nos. 16 to 27.

From this table alone it is seen that :

(a) The Yorkshire cokes are distinct from those of South Wales or Durham and of higher reactivity, whether R_I , R_{II} , or R_{III} be taken as the criterion.

(b) There is reasonable similarity between the figures obtained

TABLE III.—*Reactivities of Commercial Cokes.*

Sample Number.	Coke.	Reactivity.			Sample Number.	Coke.	Reactivity.		
		I.	II.	III.			I.	II.	III.
1	S. Wales	62	56	41	20	Yorkshire	175	165	68
2	S. Wales	69	69	40	21	Yorkshire	164	156	104
3	S. Wales	48	48	33	22	Yorkshire	84.5	84.5	84.5
4	S. Wales	73	67	42	23	Yorkshire	135.5	...	122
5	S. Wales	90	...	52	24	Yorkshire	125	77	80
6	Durham	80	63.5	60	25	Yorkshire	152	97	68
7	Durham	48	43	43	26	Yorkshire	138	112	95
8	Durham	73	67	32	27	Derbyshire	138	123	122
9	Durham	72	63	48	28	Special coke	66	57	57
10	Durham	98	72	57	29	Yorkshire	162	132	121
11	Durham	78	...	51	30	Special coke	134	116	99
12	Durham	90	...	58	31	Special coke	128	122	122
13	Durham Beehive	63	50	44	32	Durham (poor)	123	119	48
14	Middlesbrough Beehive	70	67.5	67.5	33	Durham (abnormal)	89	...	22
15	Yorkshire Beehive	43	40	42	34	Horizontal retort gas coke	145	131	78
16	Yorkshire	150	90.5	90	35	Horizontal retort gas coke	104	...	47
17	Yorkshire	170	156	70	36	Horizontal retort gas coke	120	...	107
18	Yorkshire	168	156	53	37	Vertical retort gas coke	93	...	80
19	Yorkshire	176	156	105	38	High-temperature briquette	170	150	106

for South Wales and Durham cokes. In both these classes R_I was never greater than 100, and R_{III} never exceeded 60. With the South Wales cokes the mean R_I and R_{III} are 68.4 and 41.6 respectively; corresponding mean values for the Durham samples are R_I 78.4, and R_{III} 49.9.

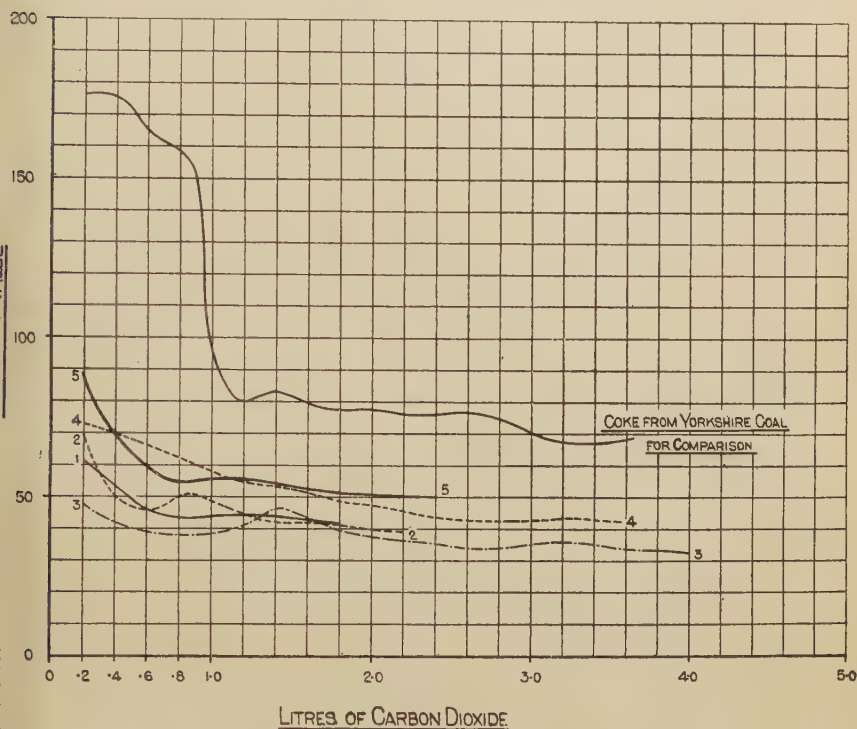


FIG. 3.—Cokes from South Wales Coals.

(c) Although there is considerable overlapping of South Wales and Durham cokes, the latter give slightly higher average values. (The average values for the Yorkshire cokes are R_I 150, and R_{III} 84.5.)

If the results be expressed graphically these points stand out clearly. The curves show the values obtained during the continued passage of carbon dioxide from R_I to R_{III} , and the shapes of the curves enable a distinction to be drawn between Yorkshire and South Wales or Durham cokes.

Fig. 3 shows the results obtained with the South Wales cokes, a curve of a Yorkshire coke being added for the purpose of comparison. It will be seen that all the South Wales cokes give similar curves. Fig. 4 shows the Durham cokes plotted in the

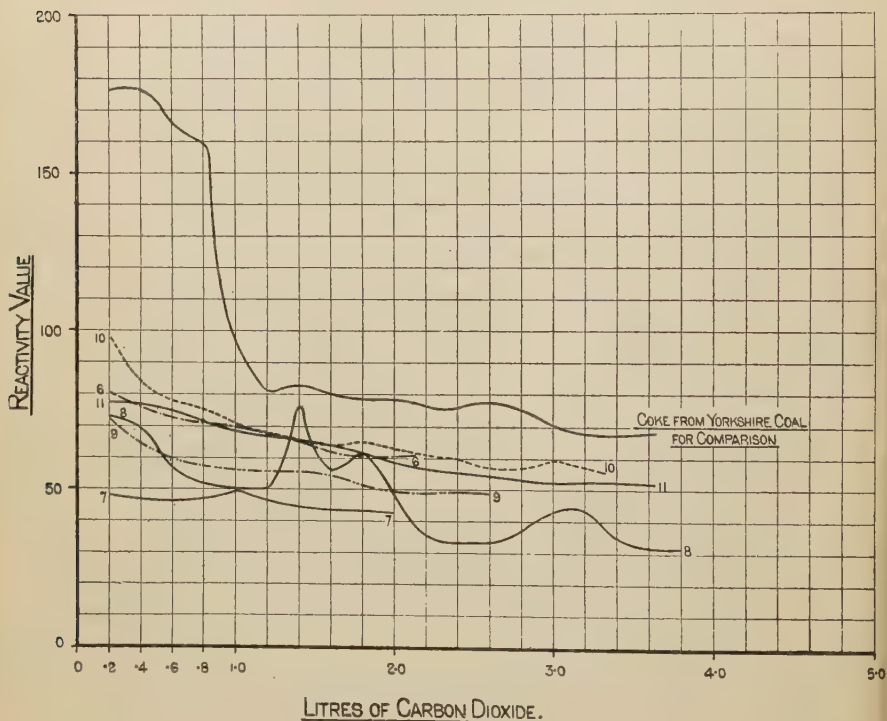


FIG. 4.—Cokes from Durham Coals.

same manner. There is less uniformity than with the South Wales samples, but the average slopes of the curves are similar, and quite distinct from that of the Yorkshire sample.

The results obtained with the Yorkshire cokes are shown in Fig. 5. With two exceptions they give curves which show a sharp decrease after the passage of quite a small volume of carbon dioxide. This decrease stops quite suddenly, and after this stage the reactivity remains fairly constant, though distinctly higher than the R_{III} values reached by the South Wales samples.

(Most of these Yorkshire cokes could be classed as South Yorkshire, but two which give similar results are definitely not from this field, so that for the present they have all been included under one general heading. This is only a temporary generalisation.)

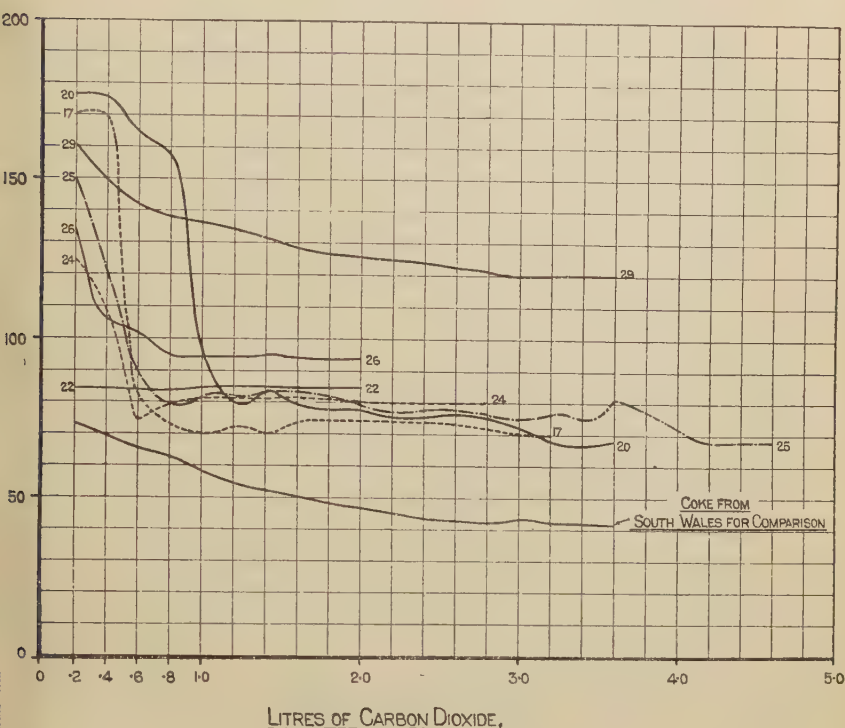
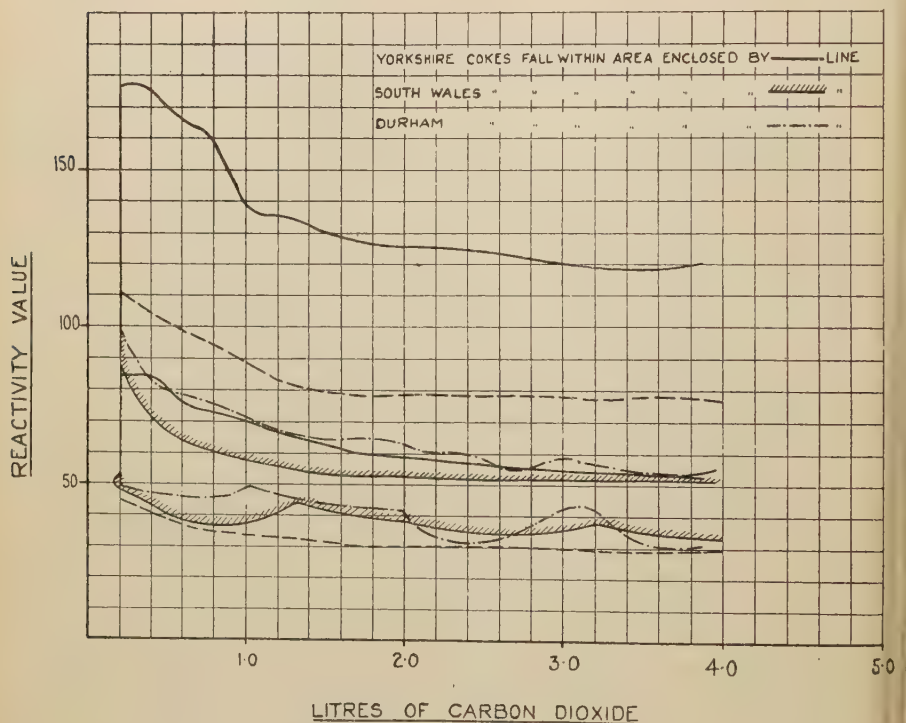


FIG. 5.—Cokes from Yorkshire Coals.

Fig. 6 shows the comparative reactivities of the three groups of cokes. In this graph the areas covered by all the cokes so far examined from South Wales, Durham, and Yorkshire are plotted. It is seen that not only are the Yorkshire cokes quite distinct from the other two classes, but they cover a larger area which is different in shape. Thus, so far as can be judged from present experience, it may be possible to distinguish Yorkshire from Durham or South Wales cokes by the results of reactivity determinations.

The reason for this is at present not clear. From information received from the National Federation of Iron and Steel Manufacturers there seems no reason to suppose that it is due to differing methods of carbonisation in these districts, and thus it may be



work now in progress in connection with the effect of the composition of ash on reactivity makes it appear possible that this is a most important factor, but no definite statement can yet be made. It can, however, be stated that after treatment with hydrochloric acid for a period of three days, during which 0.59 per

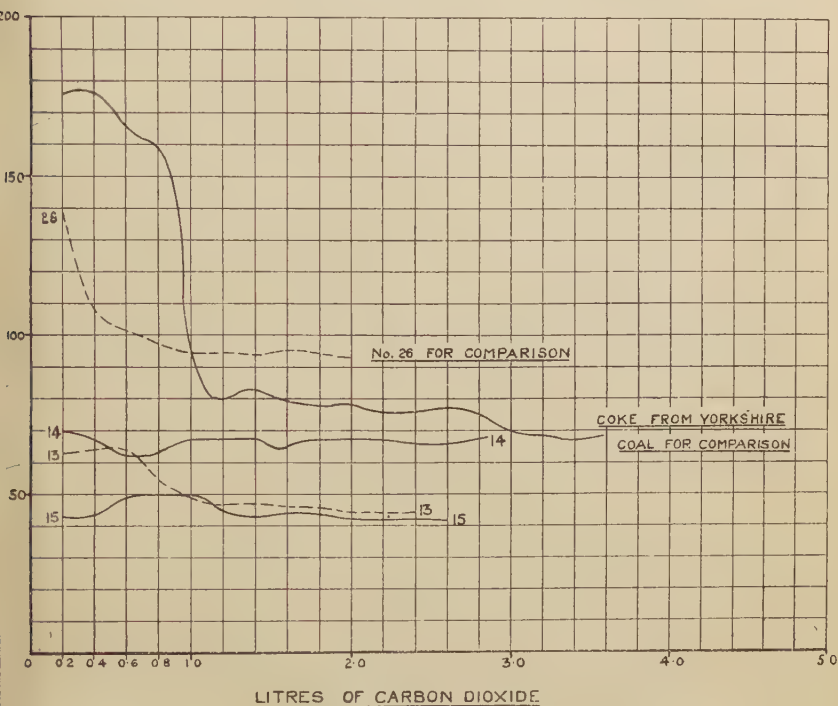


FIG. 7.—Beehive Cokes.

cent. of iron was removed, coke No. 17 gave an entirely different curve, with a constant value of 49, and without any signs of the steep initial decrease previously obtained.

Fig. 7 shows the results obtained with the three beehive cokes examined. In two cases there is no significant difference between R_I and R_{III} , while in the other case after a slight initial decrease the curve is flat. In this connection, coke No. 26 is of interest, for it was made from the same coal as No. 15, but was carbonised in a by-product oven. Nos. 22 and 24 were separate

samples of what was presumably the same coke ; it will be seen that they gave similar results, save that in one case no initial decrease was obtained. There is thus a possibility that quite small carbonisation differences may have a marked effect on the shape of the curve obtained.

CORRELATION OF REACTIVITY WITH SHATTER TEST RESULTS.

The Midland Coke Research Committee are engaged in an investigation of the shatter values of metallurgical cokes, and reactivity determinations have been carried out on some of the cokes which they have used. Up to the present it has only been possible to obtain reliable shatter values for sixteen of the cokes tested, but results so far obtained make it appear doubtful whether any close connection exists between these values. Table IV. shows the results of shatter tests conducted by Mr. R. A. Mott on six cokes.¹

TABLE IV.—*Reactivities and Shatter Tests of Six Cokes.*
(R. A. Mott.)

Coke No.	Reactivity.		Shatter Test (on 2 in.).
	I.	III.	
4	73	42	% 93.9
9	72	48	81.9
10	98	57	73.2
24	125	80	71.3
32	123	48	69.3
29	162	121	62.1

In this case it will be seen that a high reactivity corresponds with a low resistance to shatter and *vice versa*. This has not been verified with samples received from other sources. Table V. gives the results obtained with four Durham metallurgical cokes.

In this case the shatter test does not appear to distinguish between the cokes to the same extent as the reactivity test, and there are no signs of correlation between the two. All these

¹ *Fuel*, 1927, vol. vi. p. 244.

cokes were good metallurgical samples, and it was observed that the best fuel was that which gave the smoothest and most regular curve, and *vice versa*.

TABLE V.—*Reactivities and Shatter Tests of Four Durham Metallurgical Cokes.*

Coke No.	Reactivity.		Shatter Test (on 2 in.).
	I.	III.	
6	80	60	% 80·0
7	48	43	80·5
8	73	32	82·5
13	63	44	85·0

Cokes Nos. 16 to 21 were samples drawn from the top, middle, and bottom of two ovens and are compared in Table VI :

TABLE VI.—*Reactivities and Shatter Tests of Six Yorkshire Cokes.*

Coke No.	Reactivity.		Shatter Test (on 2 in.).
	I.	III.	
16	150	90	% 81·5
17	170	70	72·7
18	168	53	50·0
19	176	105	74·7
20	175	68	69·5
21	164	104	62·3

It would therefore appear that, from the data available, no correlation between shatter test and reactivity can be detected. The merit of the shatter test as a method for gauging either the hardness or the quality of blast-furnace cokes is still undergoing investigation, and much data from actual blast-furnace practice will have to be obtained before the comparative significance of the two tests can be discussed.

Reliable data as to the performance of cokes in the blast-furnace are obviously extremely difficult to obtain, but from such general information as can be placed at the authors' disposal by the National Federation, it would appear that low values of R_I and R_{III} are desirable. As far as can be judged from the present samples, what may be termed the best metallurgical cokes have reactivity values which lie within the dotted area in Fig. 6.

The gas cokes are added purely for the purpose of comparison. They are not representative, and it is not intended to indicate that vertical retort coke is less reactive than the horizontal variety. It is seen that they give lower figures than some of the Yorkshire samples. There is, however, no comparison between the shatter test figures of these two classes, the poorest Yorkshire samples being more resistant to shatter than any of the gas cokes tested.

The fundamental, and perhaps more important, side of the question of coke reactivity, is the study of the phenomena of the reaction. Without a full knowledge of this and of the influencing factors, it is at present impossible to explain many observations which have been made in the course of the examination of commercial samples. Similarly, the full significance of the reactivity values as a measure of the industrial value of coke for any given purpose cannot be fully realised until this portion of the work is complete.

The present research, apart from the collection of data regarding cokes of known industrial value, is concerned mainly with the explanation of the decrease in reactivity from R_I to R_{III} , and with the phenomenon of reactivation. The latter may be defined as a transient activation which takes place under certain conditions, and which, although it has no effect on the ultimate value of R_{III} , may cause the curve from R_I to R_{III} to be discontinuous.

This section of the research is very complicated, and it was thought desirable to present a brief summary of progress, although no adequate explanation is yet in sight.

R_{III} appears to be definitely characteristic of a coke, and shows a remarkable persistence. It can be obtained from R_I

by means other than the action of carbon dioxide, that is, by treating the coke with :

(a) A comparatively small volume of methane at 950° C.

(b) A comparatively large volume of carbon monoxide at 950° C.

(c) Oxygen at 450° C., which produces a definite increase in reactivity. If this activated coke be then treated with carbon dioxide at 950° C., a constant value is obtained approximating to the original R_{III} . (This treatment with oxygen at 450° C. forms the basis of a comparative method which has been devised for the determination of the combustibility of coke.)

Values lower than R_{III} are obtainable only in special circumstances, as, for example, when a coke is treated with such a volume of carbon dioxide that it suffers a relatively large loss in weight (the bulk density being reduced). The rate of decrease of reactivity is much slower than that from R_I to R_{II} , and when the latter value is small is only slight after some 30 per cent. of the coke has been gasified.

Any theoretical treatment of the subject must be capable of explaining the phenomenon of reactivation which may be obtained during the stage between R_I and R_{III} . This stage usually extends over a period of two or three days, during which it has been customary to allow the coke to cool down overnight in an atmosphere of nitrogen. This interruption has no apparent effect in the majority of cases, the curve of values being smooth and continuous. With certain cokes—less than 10 per cent. of those examined—it has been found that the first value obtained after reheating (in nitrogen) is much higher than the last value obtained the previous day; it may even exceed the original R_I . This high value is not maintained, and after one or two determinations the reactivity falls to the same value as before the interruption, and the curve proceeds smoothly. This abnormal behaviour has no effect on the magnitude of R_{III} ; duplicate experiments, in one of which a coke is allowed to reactivate, while in the other the determination is continuous, show that the same value for R_{III} is reached in both cases. No example of reactivation has yet been found when the coke is cooled down in the presence of carbon dioxide instead of nitrogen. It is an interesting

fact that pronounced reactivation of this type has been found only in cokes made from Durham coals.

A further difficulty encountered is that, with our present knowledge, there is no certainty that a given set of conditions will promote reactivation. With the exception of one abnormal coke, it is not yet possible with normal procedure to produce

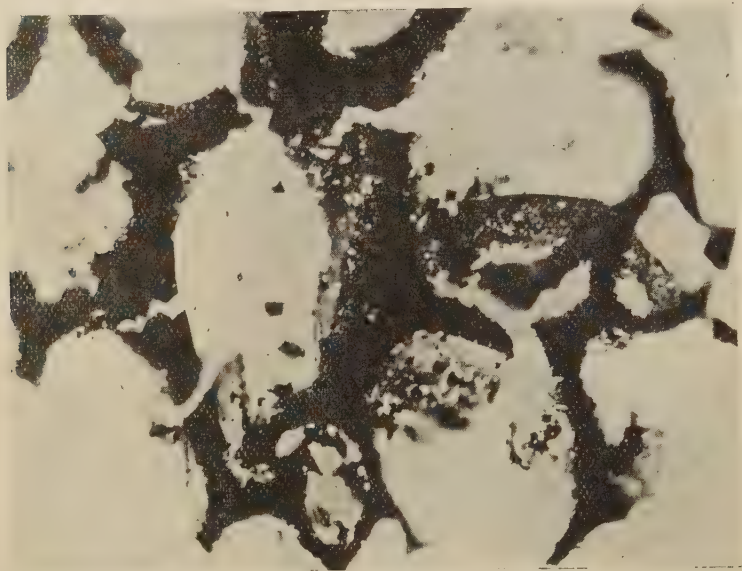


FIG. 8.—Portion of a Cenosphere after Subjection to a Reactivity Test. $\times 280$.

reactivation at will, and beyond the assertion that a coke which has once reactivated is liable to do so again no specific statement can be made. The initiation of reactivation in cokes which do not normally exhibit the phenomenon has been achieved by reducing the pressure to less than 1 mm. of mercury at $950^{\circ}\text{C}.$, but here again, as with the nitrogen treatment, there is as yet no certainty that the desired effect will be attained.

Perhaps the most remarkable aspect of reactivation is its evanescent nature. It has been observed that a coke which has activated to 170 from an R_{III} value of 30 has, after the passage of only 300 ml. of carbon dioxide, again given a value of 30. To

obtain such a decrease with normal working would necessitate the passage of at least five times this amount of carbon dioxide. The fugitive nature of the change is emphasised when determinations are made on an active charcoal or even on a coke which has been rendered more reactive by the treatment previously mentioned.

A phenomenon which may bear some relationship to reactiva-

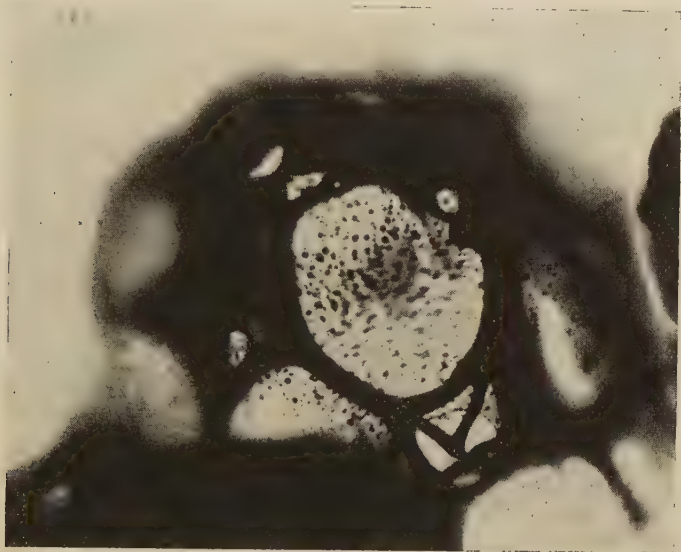


FIG. 9.—“Window” of a Normal Cenosphere before Reactivity Tests. $\times 180$.

tion has recently been observed. Many cokes previously reduced to the R_{III} condition by prolonged passage of carbon dioxide, after storing in air for a period of a year, give a reactivity value of the order of the original R_I . Subsequent treatment with carbon dioxide (the normal amount) will then reproduce the condition in which an R_{III} value is obtained.

The work in progress tends to show that the ash of the coke may have an effect, not only on the ease of reactivation, but also on the values of R_I and R_{III} normally obtained. It seems that the only hypothesis which can furnish a reasonable explanation is one having for its basis the adsorption of a gaseous film by the

active surface of the coke, for the small amount of heat treatment and passage of carbon dioxide which is necessary to produce the rapid decrease after reactivation precludes the possibility of any change in the carbon modification, and it is difficult to reconcile any theory of carbon deposition with either reactivation or the gradual increase in reactivity from R_{III} which takes place after prolonged storing of the coke at room temperature. Assuming the active surface of the coke to be discontinuous, and to consist of a number of active spots, the decrease from R_I to R_{III} can be explained, and a possible suggestion advanced for the phenomena of reactivation, low-temperature oxidation, and the slow room temperature increase.

An investigation now proceeding at H.M. Fuel Research Station on the carbonisation of coal in the form of small particles—cenospheres¹—may prove of considerable assistance. Results obtained by Mr. H. R. Leech show that, after a cenosphere has been subjected to exactly the same treatment which suffices to bring a coke from R_I to R_{III} (a constant reactivity value is actually obtained), its surface is pierced by a number of minute holes, mostly in the “window” or transparent portion of the particle, but some of which actually penetrate the framework. It is proposed to study the effect of progressive treatment with carbon dioxide, and to make further examination after similar treatment with methane and carbon monoxide. The perforations may be observed in Fig. 8. Fig. 9 shows the “window” of a normal cenosphere before “reactivity” treatment.

¹ H. E. Newall and F. S. Sinnatt, *Fuel*, 1924, vol. iii. p. 424. F. S. Sinnatt, *Transactions of the Institution of Mining Engineers*, 1927, vol. lxxiii. p. 147.

DISCUSSION.

Dr. R. LESSING (London) opened the discussion by pointing out to practical men that what were seemingly academic methods of treatment of the various problems were, as work was going along to-day, very essential. The same criticism might be levelled against the present paper as had been levelled against that of Messrs. Evans and Bailey, but it was necessary to apply methods which on the face of them might not appear very practical, in order to get at the fundamentals of the many problems that were involved in blast-furnace practice, as in many other industrial operations, in order to bring some daylight into the complexity of the factors involved.

The factor dealt with here had given rise to a great deal of discussion during the last few years. Despite the results which had been brought forward, it was still a moot question whether a high reactivity of coke to the attack of carbon dioxide, as distinct from the combustibility of coke by oxygen or air, was to be desired or not. The paper did not make it quite clear whether coke should be highly reactive or not; it did, however, furnish one item in the chain of evidence as to the difference in the behaviour of cokes in the blast-furnace or in other metallurgical work. In the past, cokes had been merely regarded as so much carbon mixed up with so much inert material, with just a casual attempt at gauging their quality empirically by their physical strength. Those tests were now being elaborated, and the question of chemical and physical characteristics and strength had to be correlated.

One factor which seemed to him to influence the reactivity and combustibility, and even the physical character, of coke to a very great extent was the ash. He had pointed out on many occasions, and had had the privilege of doing so at a previous meeting of the Institute, that the ash in coke was of very considerable importance, and still more so the absence of ash. On the purely economic side it had been calculated, first by Mr. Lewis and recently by Mr. Gill, that, taking merely the economic influence, the debit value of ash in coke amounted to a considerable figure. His own work showed that the removal of ash was now commercially possible to an extent hitherto considered unobtainable. It was now possible to prepare from ordinary slack coke containing from 3 to 5 per cent. of ash, and its use in the blast-furnace would make a difference in the cost of pig iron production of 6s. to 7s. as compared with present-day coke. Those calculations took into account the limestone required, the amount of slag produced, and the cost of its disposal; but in the absence of evidence to that effect they could not possibly take into consideration the incidental advantages such as the faster driving of the furnace, the greater purity

of the iron made, and the greater interaction between the coke and ore by reason of higher combustibility. This showed the need of studying the question of the inorganic constituents of the coke more intensively. Another problem was that the differences in reactivity which were undoubtedly shown in different districts by the results obtained by the Fuel Research Station and the work of others, were closely bound up with, if not entirely due to, the ash in the coke. He ventured to suggest that the very striking differences which were shown in the paper to exist between cokes obtained from Durham or Welsh or Yorkshire coals had something to do with the type and quantity of inherent ash in the coal. It was known that the method of coking could not make those differences, because the same type of coke-ovens were being used in all districts, but the coals were different. The inherent ash in Yorkshire coals was something like 1 or 2 per cent., and it was possible to obtain coal of those ash percentages to-day on a commercial scale. In Durham it was slightly higher, but the difference in the composition of the ash might be even a greater factor, because it was known from past work that in the coking process the ash constituents had a catalytic effect on carbonisation; they could direct the breaking up of the coal, for instance, in one direction or another; they could make the coke denser or less dense, or make it of one variety or another, and it was especially in that direction that it was necessary to look for more information in order to explain the phenomena produced by the authors. He desired to pay his tribute to the paper as a useful contribution to the knowledge of the subject.

Mr. E. C. EVANS (London) stated that existing methods of testing the comparative values of blast-furnace cokes were not completely satisfactory. A number of methods of coke examination were now being investigated by the Coke Research Committees established at different centres, but no test had yet been found which could be relied upon, in itself, to give a definite measure of the value of coke for blast-furnace purposes.

The method described in the paper was worthy of serious investigation. It allowed of a very accurate comparison of certain properties of coke, a comparison much more accurate, in fact, than could be obtained by a test, for example, of the character of the shatter test, and if the results of the reactivity tests could be correlated in any way with those of blast-furnace trials, the method proposed, after simplification, would be one of considerable service to the industry.

Mr. D. SILLARS (Middlesbrough) said the investigation under discussion had been started many years ago. Sir Isaac Lowthian Bell had done very much the same thing, but with far less accuracy; yet he did not come to very different results from what were shown in the paper. The difference between one coke and another, so far as it was revealed by their reactivities, was a sort of difference very well known

to the works, although they were in the dark. That was not a criticism of the results, but rather an indication to the authors that before very much could be said about the effect of the results given it was necessary to consider cokes which were far less widely different from one another than the three groups they had chosen. The resemblance between the Durham and South Wales curves was, he thought, not greater than could be found between one South Wales coke and another South Wales coke, or one Durham coke and another Durham coke; to get results it was necessary to split up the results for cokes from the same district. With regard to the authors' decision to take 950°C . as their reaction temperature, that was, of course, quite right from the point of view of reactions taking place in the shaft of the furnace, but he wondered if they had taken any figures at very much higher temperatures, of the order of 1400°C ., in order to find out whether, as one would almost expect when there was a rise in temperature like that, they would not find the reactivity of one coke compared with another gradually close down until they got similar results at a higher temperature. The hearth operation took place at gradually increasing temperatures, and it would very much delimit the range of inquiry if it were found that, at a certain temperature higher than 950°C ., even those results began to show the same type of curve. He thought the particular merit of the paper was that the authors had not attempted to draw any conclusion at the present time. Some five or six years ago there had been in the blast-furnace world a feeling of considerable uncertainty concerning the quality and behaviour of coke; fortunately that state of affairs had now passed away. A more serious attack was being made upon the problem of the quality of coke, and that, correlated with the work of the various Research Committees in the country and the work recorded in the paper, would be of the very greatest value.

CORRESPONDENCE.

Professor J. H. ANDREW (Glasgow) wrote that whilst he appreciated the difficult piece of work which the authors had carried out, he would like to offer a few comments relative to the methods employed by them. He contended that they had obtained neither a true practical nor a theoretical value for the reactivity. If they had wished to obtain a practical value, would not the obvious method to be employed be to pass over the coke samples a current of gas of the same composition as that existing in normal blast-furnaces within the particular temperature zone corresponding to their selected temperature for the determinations? Again, if a theoretical figure was desired, would it not have been better to have passed a known quantity of CO_2 over finely powdered coke? He could not quite understand why the coke

samples were first of all treated with nitrogen prior to passing over the CO_2 ; would it not have been better to drive off the hydrocarbon gases by an initial heating *in vacuo*?

The reactivity of any carbonaceous material must surely depend upon the surface exposed to the reaction, and the rate of the reaction $\text{CO}_2 + \text{C} = 2\text{CO}$ must be dependent upon the surface area. If this surface were allowed to adsorb nitrogen, or when the surface had an adsorbed layer of CO, it was to be expected that the reactivity value would change. Further, the low partial pressure of CO_2 in the blast-furnace would tend to increase the amount of CO. The question of adsorption, even at the temperature employed, could not be overlooked, and might well account for the initial drop in reactivity with time, and for the reactivation of coke previously reduced to its normal value.

It would be extremely interesting if the authors would examine the ash of their different samples with a view to ascertaining whether reactivity depended upon the agency of the ash acting as a catalyst.

He wished it to be understood that he in no way desired to belittle the work of the authors, which, when the difficulties involved were appreciated, stood out as an excellent piece of experimental work. He would like his criticism to be regarded as constructive rather than destructive.

The AUTHORS, in reply, expressed their high appreciation of the kind remarks of Dr. Lessing, and of the importance of his suggestions. In projecting the work it was considered that the first step necessary was to develop a method of determining the reactivity of coke with such a degree of accuracy that small differences could be detected. That might be considered as a preliminary to the investigations of the broader problem, which consisted in the dissection of the factors contributing towards reactivity. Experiments had already been carried out which indicated that the influence of the inorganic constituents upon reactivity was appreciable, but until that avenue had been investigated in detail it was premature to attempt to relate the results with the properties of the coal from different localities.

The authors thought that the remarks of Mr. Evans were very much to the point, and they recognised the difficulty of correlating the results obtained in the investigation with the values of coke for blast-furnace purposes. They felt, however, that they must enlist the aid of those familiar with the details of blast-furnace operations, if such a correlation were to be made possible.

In reply to Mr. Sillars, as already mentioned in the reply to Dr. Lessing, the objects of the investigation might be considered as two-fold: first, to attempt to correlate a simple determination of reactivity with the values of coke for blast-furnace purposes; and, secondly, to attempt to dissect in detail the factors which went to make up the properties of coke in relation to combustion. It was necessary to adopt

experimental conditions which could be used in ordinary laboratories and which would yield differences among the various cokes which could readily be measured. No work had yet been attempted by the authors at temperatures of the order of 1400°C ., but reference might be made to the work of Arend and Wagner,¹ and also to that of Korevaar.² It would appear that the differences found at 950°C . would be so reduced at a temperature of 1400°C . that the object of the test would be defeated.

In reply to Professor Andrew, the authors, in consultation with Mr. Evans, decided upon the conditions adopted in the test, and considered that it was impracticable to attempt to imitate the conditions prevailing in a blast-furnace. It was felt that the use of pure carbon dioxide was preferable to a mixture of carbon dioxide, carbon monoxide, and nitrogen, owing to the uncertainty introduced by the effect of the mixture of gases. They considered the question of the size of particles in detail, and adopted the size of coke as one convenient for laboratory operations, and one in which the original structure of the coke had not been completely destroyed by crushing. It did not appear possible with our present knowledge to determine or calculate the actual surface area of the particles of coke, so that, contrary to Professor Andrew's surmise, no theoretical advantage would accrue in the use of finely divided coke.

In carrying out the test, nitrogen was used because it was the most inert gas generally available, and the preliminary heating was necessary in order to remove volatile matter from the coke. That appeared to be a simpler operation for ordinary chemical laboratories than evacuation. In many cases Reactivity II determined after evacuation was practically identical with the value obtained by prolonged treatment with nitrogen. In other cases, however, the use of a vacuum did introduce the complicating factor of reactivation. It might be recalled that in the earlier part of the paper it was pointed out that many other aspects were being explored.

¹ *Revue de Métallurgie, Mémoires*, 1924, vol. xxi. p. 585; *Fuel*, 1926, vol. v. p. 106.

² *Fuel*, 1926, vol. vi. p. 92.



NEW PLANT OF THE APPLEBY IRON CO., LTD.¹

BY A. CROOKE AND T. THOMSON (SCUNTHORPE).

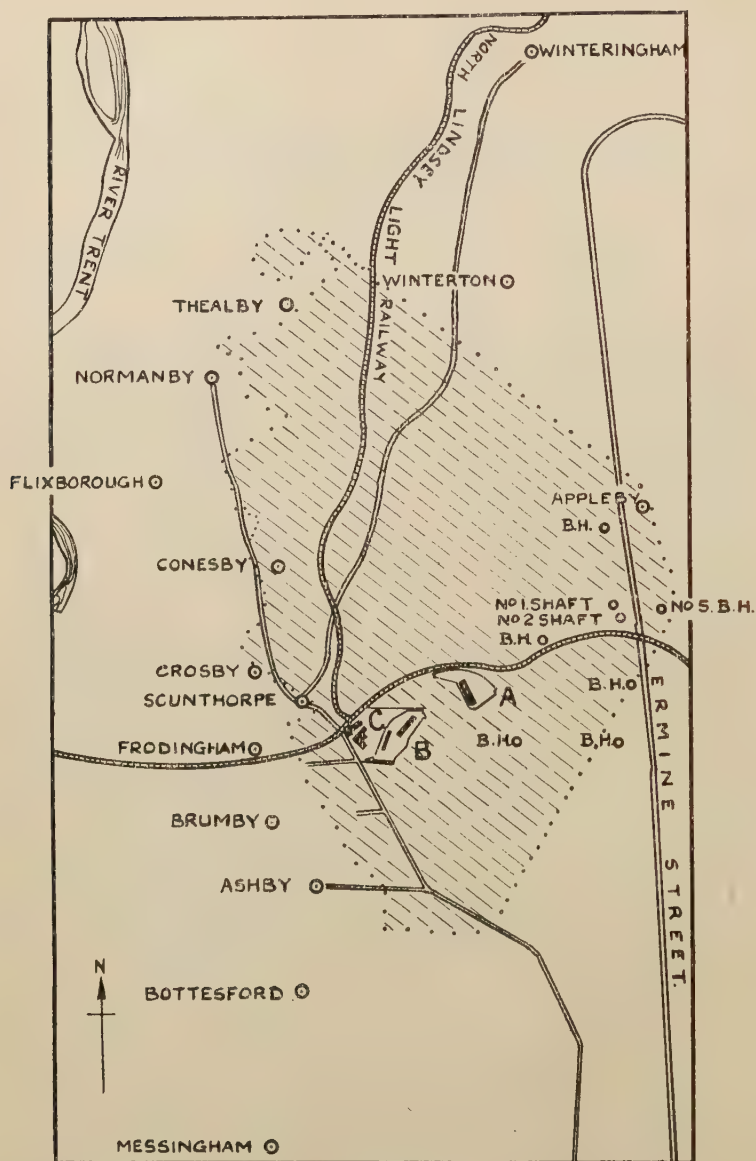
INTRODUCTION.

THE works of the Appleby Iron Company are situated near Scunthorpe, in North Lincolnshire. The selection of the site was due to the presence of the bed of ironstone known as the Frodingham bed, a deposit which was known and worked in the time of the Roman occupation of Britain, as is shown by traces of their smelting operations. Blast-furnaces, however, were not built until about 1860.

The Frodingham bed is situated in the upper part of the lower Lias, and dips to the east. Fig. 1A shows the area known to be workable. At present only outcrop stone is worked, and the deepest cover removed is about 50 ft. Fig. 1B is a section through the ore field. Towards the east, where the Frodingham bed is under deep cover, there exist two other ironstone beds, which are, however, too poor in iron to be workable. The relative positions of the three beds are the Cleveland Main Seam, 155 ft. from surface, 7 ft. 9 in. thick, containing, iron 5·5 per cent. and insolubles 47·2 per cent.; the Pecten bed, 236 ft. from surface, 2 ft. 10 in. thick, containing, iron 15·9 per cent. and insolubles 13 per cent.; the Frodingham bed, 337 ft. from the surface, 10 to 20 ft. thick, containing, iron 24 per cent. and insolubles 11·7 per cent.

The Appleby Iron Company, Ltd., formed in 1874, blew in their first furnace about 1877, and carried on the manufacture of pig iron until 1910, when the plant was closed down. At that time it consisted of four blast-furnaces, one 62 ft., one 65 ft., and two 75 ft. high. In 1912 this plant was acquired by the Frodingham Iron and Steel Co., Ltd., which had for many years carried on successfully the manufacture of steel sections. It

¹ Received February 29, 1928.



- A - APPLEBY IRONWORKS.
 B - APPLEBY STEELWORKS.
 C - FRODINGHAM IRON & STEEL WORKS.

FIG. 1A.—Sketch Map of Frodingham Ore Field. (*Geological Survey of England and Wales, Special Reports, vol. xii., "Iron Ores."*)

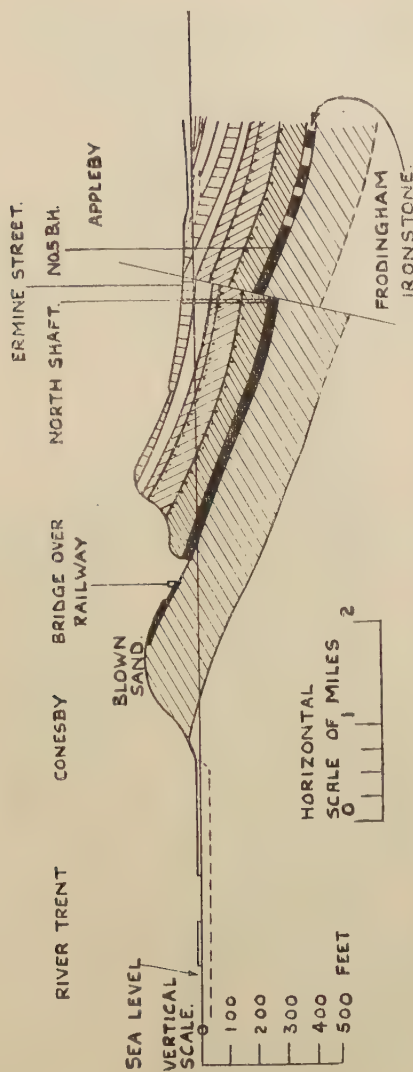


FIG. 1B.—Section through Frodingham Ore Field. (*Geological Survey of England and Wales, Special Reports, vol. xii., "Iron Ores."*)

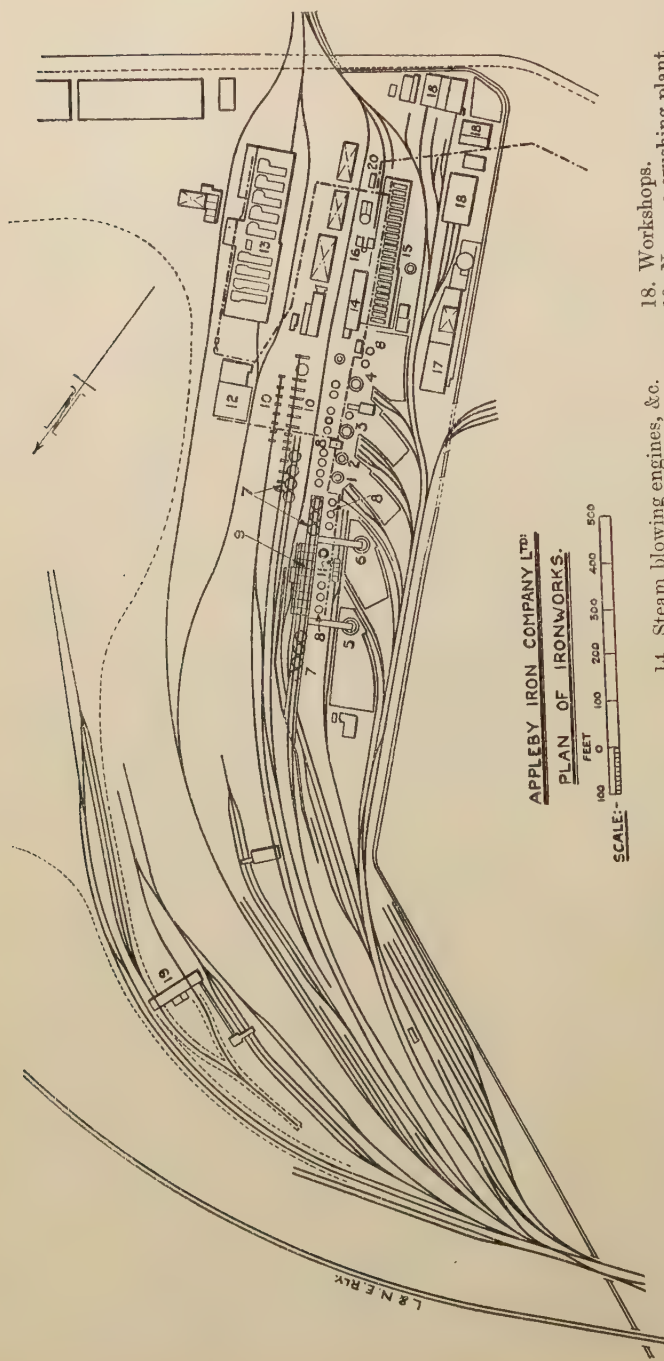


Fig. 2.

was desired to extend operations to include the manufacture of steel plates, in the belief that the sale of these two products would thereby be mutually promoted. Preparations were made for additions to the blast-furnace plant and for new steelworks in 1914, but it was not until 1917 that the work was actually put in hand.

Unfortunately the shortage of men and materials at that time was so great that the works were not completed before the trade slump in 1921. Operations then had to be suspended and were not resumed till 1926. The first of the new blast-furnaces was blown in during January 1927, and at the same time the first steel was made and the first slabs and plates rolled.

IRONWORKS.

Blast-Furnaces.

The arrangement of the blast-furnace plant is shown in Fig. 2.

Four blast-furnaces were taken over from the original Appleby Company, with their equipment of stoves, calcining kilns, blowing plant, &c. These furnaces are hand-charged.

Two blast-furnaces of modern design, Nos. 5 and 6, were added. These are 80 ft. high, and the charging gear is of the inclined hoist and bucket type, as shown in Fig. 3 (Plate VI.). They have ten 6-in. hearth tuyeres and five 4-in. bosh tuyeres, four rows of copper coolers, a steel bosh jacket which is sprayed with water, and ten rows of cast-iron stack coolers, which are shown in Fig. 4. Three transfer cars, each carrying two buckets, run in a straight line under ore bins, coke bins, and calcining kilns. The ironstone from the crushing plant is dumped from wagons on the top of the ore bins and kilns, the wagons being pushed on to the bins by a locomotive up a long inclined embankment. The coke bins are built into the sides of the ore bins, but the coke is dumped from a lower level than the ore. Large screens are provided at each bin; the screenings are collected by belt conveyor and passed on to an elevator which delivers them through grading screens into wagons. All the bins and kilns are fitted with gates operated by the transfer car driver.

The hoisting mechanism is operated by a d.c. motor taking

current from an a.c. supply fed through a motor-generator. The stove equipment for the two furnaces consists of six stoves, each 20 ft. in diam. by 100 ft. in height, of the two-pass Cowper type.

The gas is taken from the top of each furnace by two down-comers into a large plain dust-catcher. It is then passed through

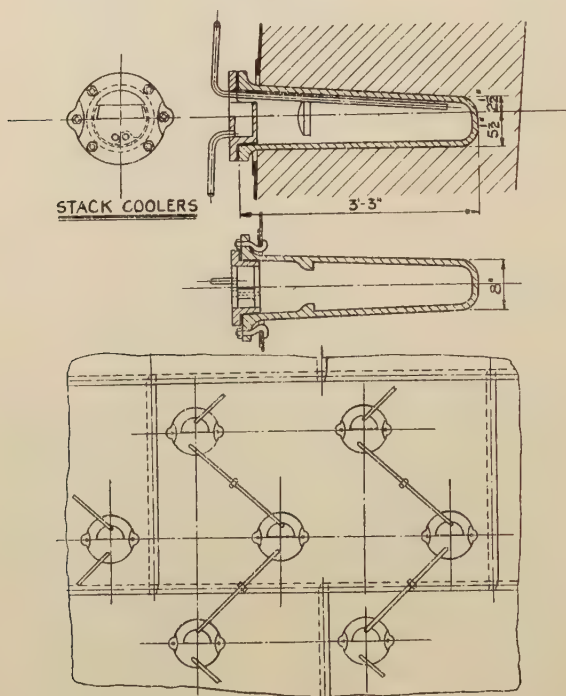
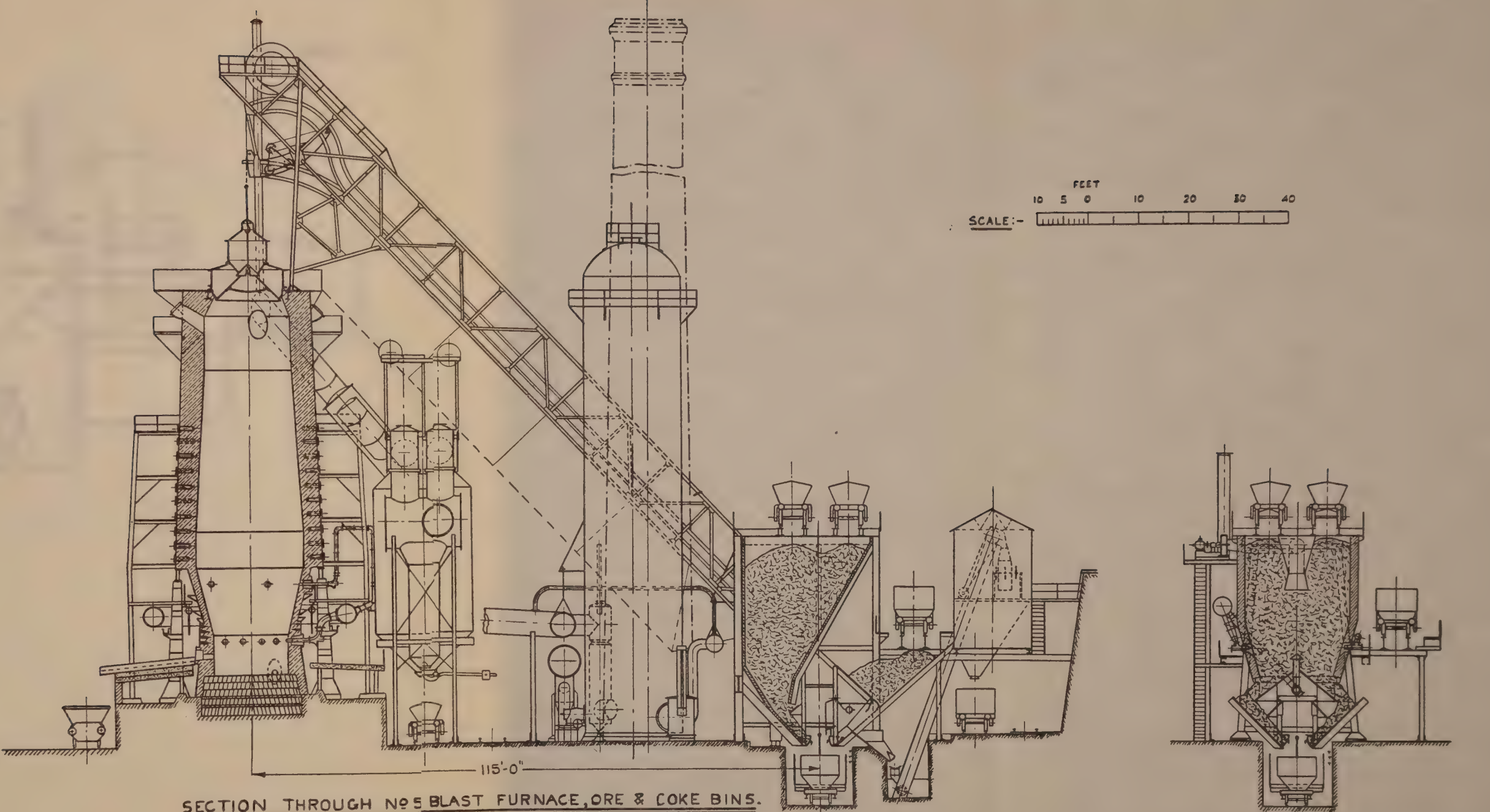


FIG. 4.

a gas cleaner of the steel mattress type, consisting of five units, capable of rough cleaning 60,000 cu. ft. of gas per min. The gas from this plant is used at the stoves and boilers. The cooling water for the furnaces is supplied from an overhead ferro-concrete tank of 75,000 gals. capacity, which also supplies the cooling water for the old furnaces.

The ore-crushing plant is illustrated in Fig. 5 (Plate VII.). The ironstone is brought from the mines and tipped into a hopper which feeds through a grizzly conveyor into a large rotary screen,

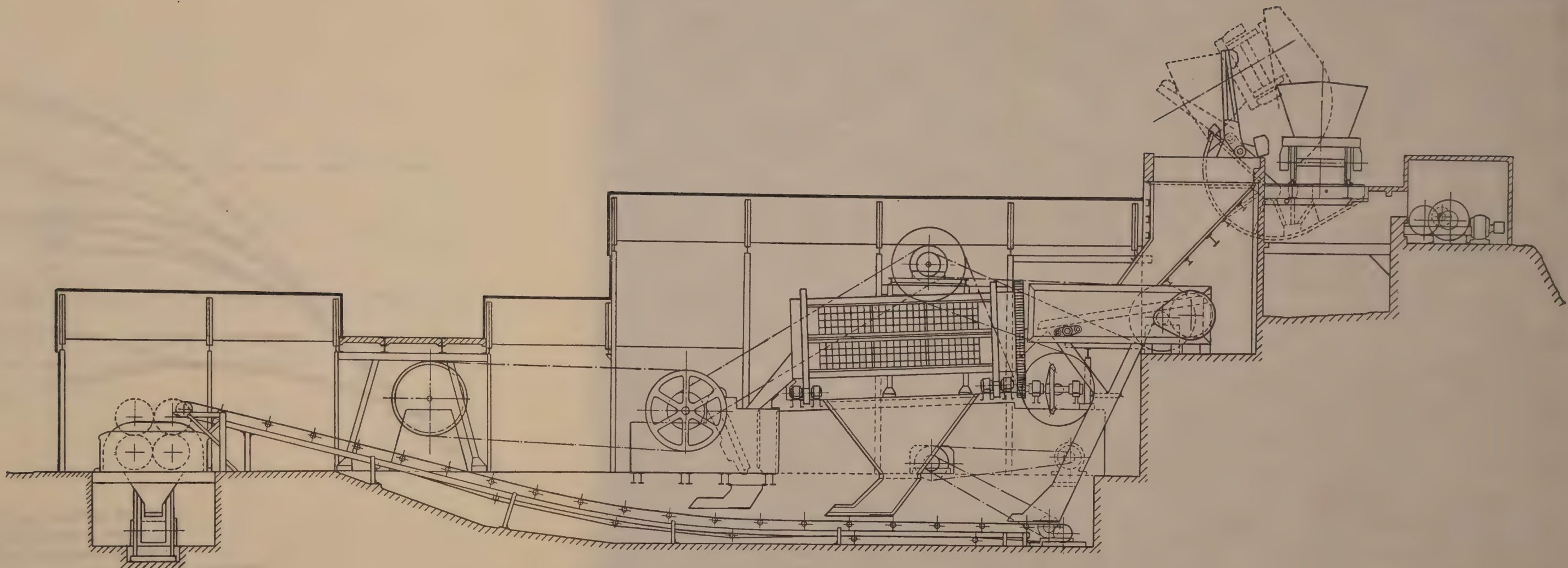


SECTION THROUGH No 5 BLAST FURNACE, ORE & COKE BINS.

SECTION THROUGH CALCINING KILN.

FIG. 3.

[To face p. 176.]



SECTIONAL ELEVATION THROUGH CRUSHING BUILDING.
ORE CRUSHING PLANT.

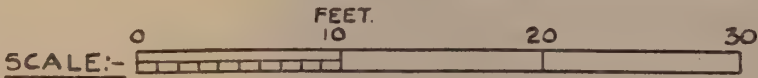
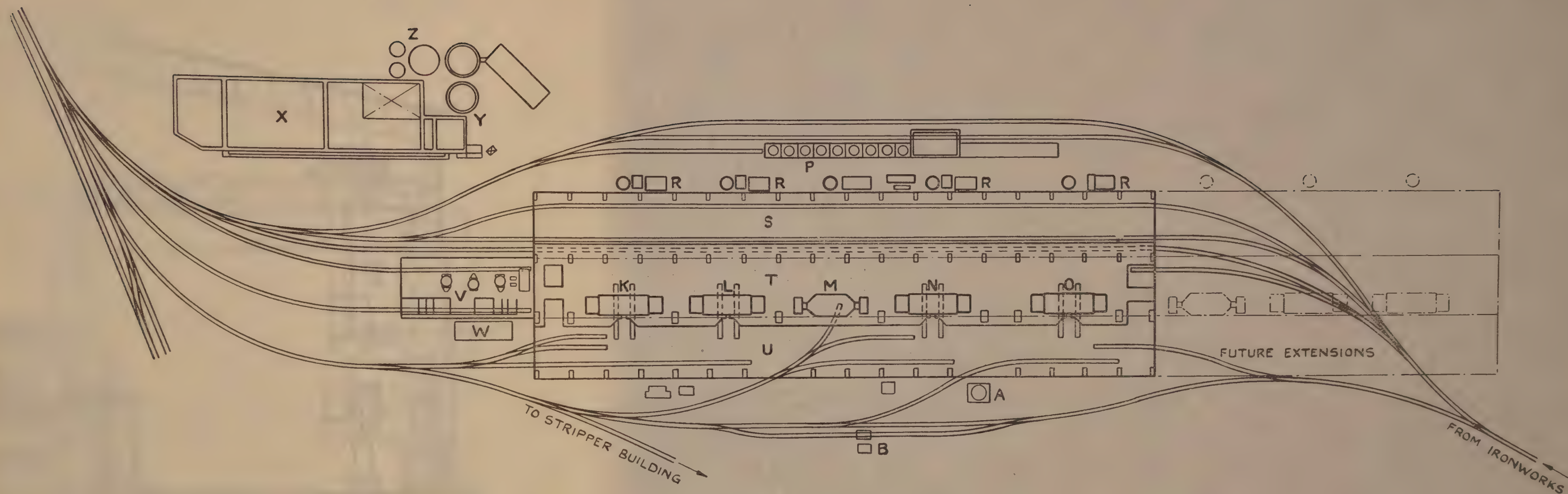


FIG. 5.



K, L, N, O. STEEL FURNACES.
 M. MIXER.
 P. GAS PRODUCERS.
 R. WASTE HEAT BOILERS.
 S. STOCKYARD BAY.

T. FURNACE CHARGING BAY.
 U. CASTING BAY.
 V. BASIC GRINDING PLANT.
 W. LABORATORY.
 X. RESERVOIRS

Y. CIRCULATING WATER PLANT.
 Z. WATER SOFTENING PLANT.
 A. HYDRAULIC ACCUMULATOR.
 B. MOLTEN IRON AND INGOT WEIGHBRIDGE.

OPEN-HEARTH FURNACE PLANT.



Fig. 6.

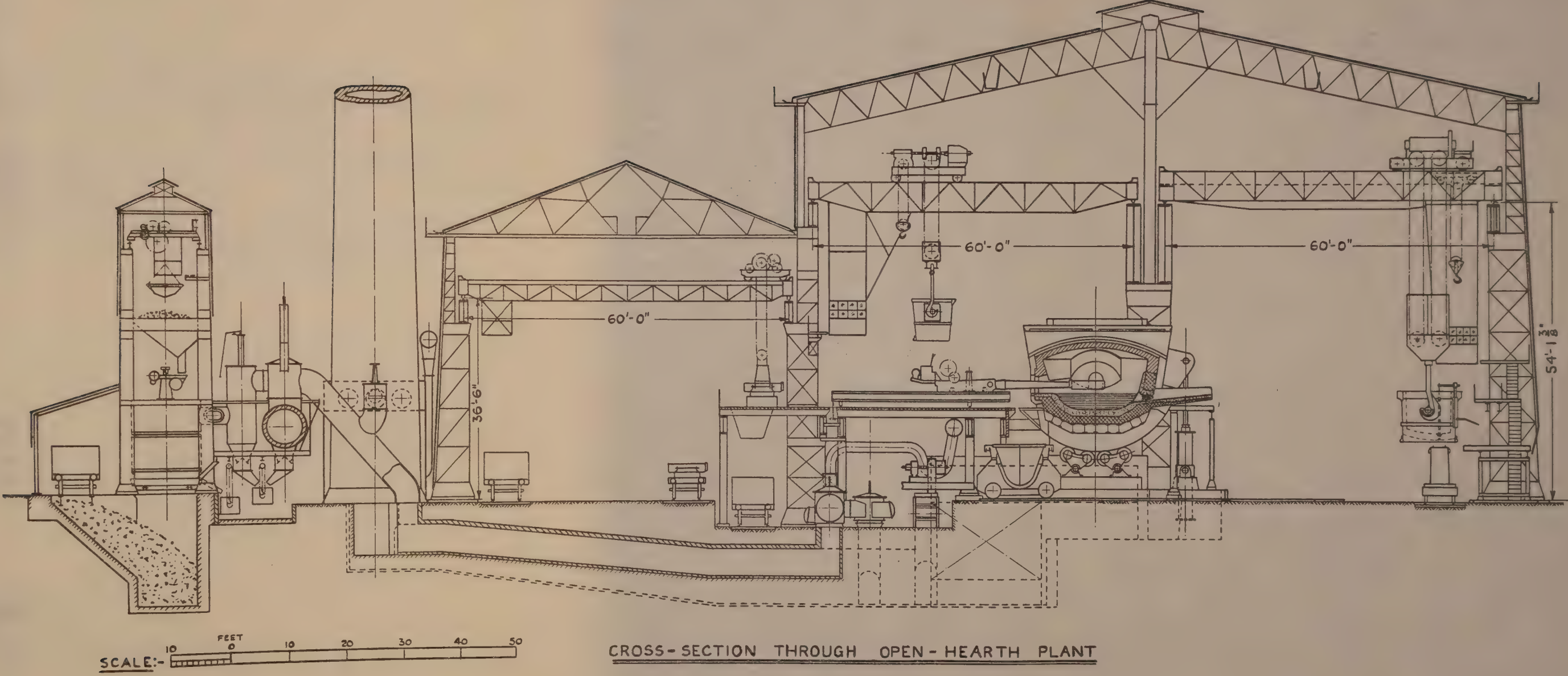


FIG. 7.

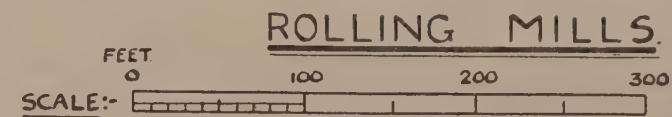
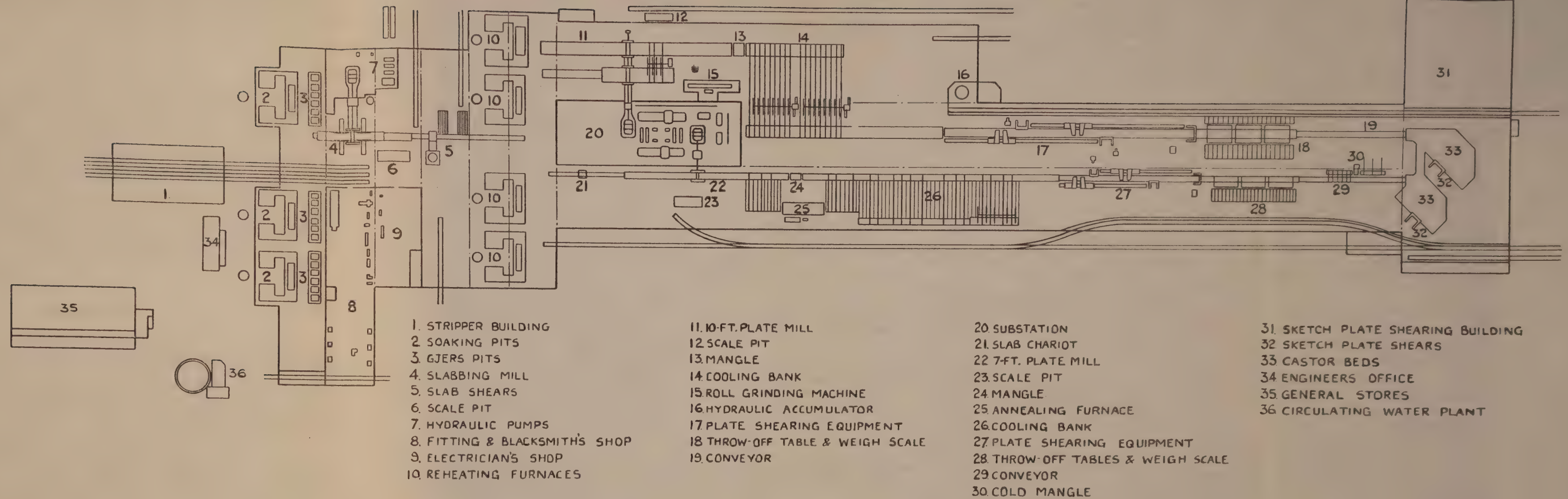


FIG. 9.

which in turn feeds into a jaw crusher. A belt conveyor collects the stone from the grizzly, screen, and crusher, and delivers into a roll crusher. A second belt conveyor collects the broken stone again, and delivers into a rotary screen, where it is graded into three sizes. The capacity of the plant is 200 to 250 tons per hour.

Blowing Plant.

This consists of two vertical steam blowing engines, each capable of blowing 18,000 cu. ft. per min. at 10 lb. pressure, and two steam turbo-blowers, each capable of blowing 28,000 cu. ft. per min. at $12\frac{1}{2}$ lb. These, with their necessary Lancashire boilers, are situated together, and may be termed the old plant, although the turbo-blowers have been installed since 1915.

The gas-driven blowing plant consists of two gas engines, each capable of blowing 28,000 cu. ft. per min. at $12\frac{1}{2}$ lb. pressure, and two gas engines, each capable of blowing 40,000 cu. ft. per min. at $13\frac{1}{2}$ lb. pressure.

Power Plant.

In the same house is placed the power plant, supplying the electrical requirements of both the blast-furnaces and the steel-works. The installation comprises five gas engines, each coupled to a 1500 kva. alternator running at 100 r.p.m. and one 3750 kva. turbo-alternator. The steam turbine is supplied with superheated steam at 150 lb. per sq. in. pressure from water-tube and Lancashire boilers, all fired by blast-furnace gas.

The clean gas for the gas engines is supplied by a cleaning plant of the Halberg-Beth type. This has four units, each capable of cleaning $1\frac{1}{4}$ million cu. ft. of gas per hour.

The auxiliary plant for the gas engines, consisting of air compressors and receivers for starting, and the circulating pumps for cooling, is placed on the basement floor level on one side of the engine house, and is easy of access from the main engine-house floor. The cooling water circulates in a closed system, the water being first forced by centrifugal pumps through the jackets and pistons of the gas engines, then pumped over a cooling tower and thence through filters back to the centrifugal pumps.

The current generated by the power plant is alternating three-phase, 50 periods, 6600 v., and the gas engines are designed to run in parallel with each other and with the steam turbo set. The alternator rotors are keyed to the crankshaft alongside the flywheels, a flange on the boss of the motor being brought against and bolted to a flange on the boss of the flywheel. The weight of the flywheel on each engine is 56 tons.

The switch house is built on one side of the power house, the main switches being of the remote control type operated electrically by low tension direct current supplied from a battery charged from an exciter set. A certain amount of the current generated is here reduced by static transformers to 440 v., and forms the main supply for the blast-furnace plant. The remainder is transmitted at the voltage generated to the steelworks at a distance of upwards of a mile from the power station.

A part of the blast-furnace gas cleaned in the Halberg-Beth cleaning plant is passed through boosting fans and transmitted through an overhead steel tube 4 ft. in diam. and about 1800 yards long to the steelworks. This steel tube is used as the support for the insulated electric cables between the power house and the steelworks.

STEELWORKS.

Open-Hearth Plant.

The open-hearth plant, a plan of which is shown in Fig. 6 (Plate VIII.), consists of one mixer of 500 tons capacity, and four tilting furnaces, three of 250 tons and one of 300 tons capacity. These are in one line, the mixer being placed between two pairs of furnaces. The building, a cross-section of which is shown in Fig. 7 (Plate IX.), consists of three bays—namely, stockyard bay, charging bay, and casting bay, each being 60 ft. between crane rails. The stockyard, which is completely covered in, has two 20-ton overhead box lifting and magnet cranes. The charger boxes are handled in special containers, each holding five boxes. The boxes, having been filled on the floor, are lifted on to an extension of the furnace platform projecting into the stockyard. The furnaces are served by two 4-ton low ground revolving type open-hearth chargers.

The hot metal is charged into the mixer in the casting bay, and is tapped in the charging bay, the metal being distributed

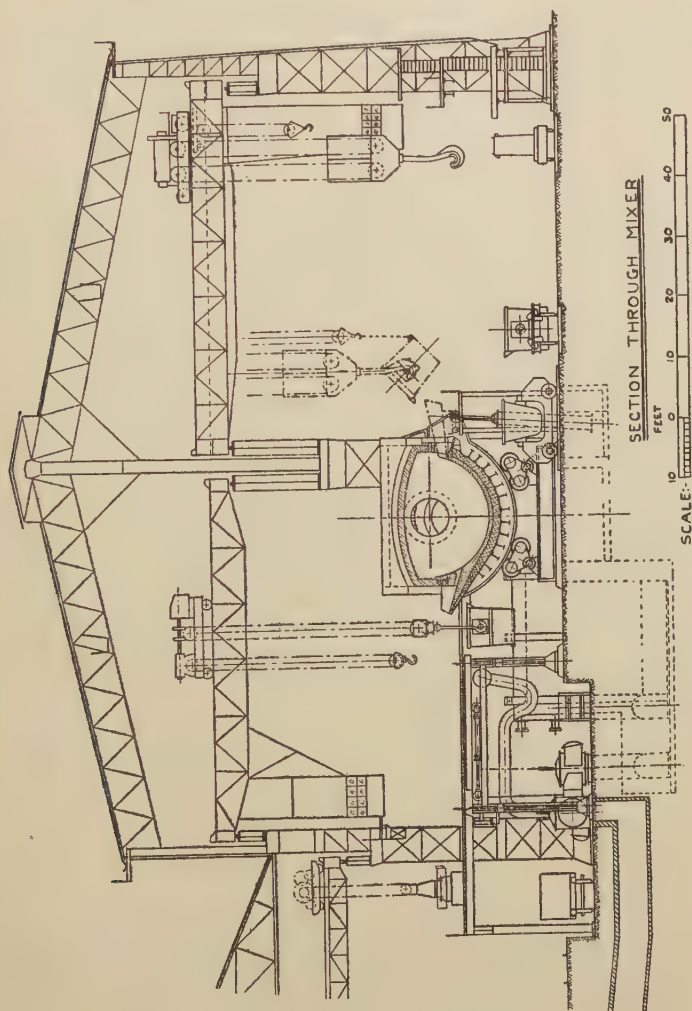


FIG. 8.

to the furnaces by two 50-ton hot metal cranes. A section through the mixer is shown in Fig. 8. The slag is taken from the furnaces on the charging side, the slag ladles being run into position from the casting bay side under and at right angles to the furnaces,

there being two tracks to each furnace. Two 100-ton and one 125-ton casting cranes are provided. The ingots are cast from the ladles in moulds set on cars which run on a standard gauge line longitudinally through the building.

The furnaces are fired by producer-gas generated by a battery of Kerpely revolving-grate producers, fitted with automatic feeders and levellers and separately blown by turbo-blowers. They are fed by a grab crane from a central coal bunker. The chimney flues from the furnaces are carried under the stockyard to the brick-built chimneys, which are 7 ft. in diam. at the top and 180 ft. high, and are placed outside the stockyard building. At each furnace a waste-heat tubular boiler is installed, each with a heating surface of 8320 sq. ft. and fitted with an induced draught fan and superheaters.

At the end of the open-hearth building is located a plant for grinding the burnt dolomite and other materials for fettling and repairing the furnaces.

The cooling water for the furnace chills is supplied from a ferro-concrete overhead tank of 75,000 gals. capacity fed by two centrifugal pumps. The return water is pumped over a wooden cooling tower attached to a large reservoir of 750,000 gals. capacity. Adjacent to this reservoir is a smaller reservoir filled from a water-softening plant, the soft water being used to feed the waste-heat boilers.

Basic Slag Plant.

A basic slag grinding plant of modern design is in course of construction. This plant is designed to reduce labour to a minimum, and it has a capacity of 100,000 tons per year.

ROLLING MILLS.

The rolling mills, a plan of which is shown in Fig. 9 (Plate X.), consist of a slabbing mill, a 10-ft. plate mill, and a 7-ft. plate mill. The ingots on cars are shunted by a locomotive into a building where they are stripped by an electrical overhead crane. The stripped ingots on the cars are pushed through into the soaking pit bay. In this bay are three gas-fired soakers, each having an ingot capacity of 100 tons, and three Gjers soaking pits without

heating, each having an ingot capacity of 160 tons. The ingots are charged by two overhead cranes, each capable of handling ingots up to 20 tons in weight. These cranes also draw the soakers and deposit the ingot direct on to the slabbing-mill rack, which is extended into the soaking pit bay.

Slabbing Mill.

The slabbing mill is an electrically driven reversing mill, with rolls 42 in. in diam. and 9 ft. 6 in. long. The mill is driven through machine-cut helical pinions and spindles having universal coupling boxes, by a motor capable of exerting a torque of 20,000,000 in.-lb. up to 48 r.p.m., and with a rating of 15,200 H.P. from 48 r.p.m. to 100 r.p.m. A separate hydraulic accumulator is provided in a closed circuit with the balancing cylinders. All the motions of the manipulators on each side of the mill rolls are electrical. The slab shears are capable of shearing up to 54 in. by 18 in., and are operated by a steam hydraulic intensifier, the steam being taken from the waste-heat boilers at the open-hearth furnaces. Beyond the slab shears hydraulic pushers are installed for dealing with crop ends and also slabs to be stocked. The scale from the mill is washed by water down an inclined duct into a large catch pit and afterwards loaded up by a grab suspended from a 5-ton overhead crane. The slabbing-mill bay is served by a 60-ton overhead crane. The slab shear bay is served by a 20-ton overhead crane which loads up the crop ends and stocks slabs.

Plate Mills.

The run-out rack from the slab shears is continued through into the reheating furnace bay. There are four reheating furnaces of the vertical soaking pit type, with sliding roof doors. Three of these furnaces are built to take slabs up to 8 ft. long, and one is made to take slabs up to 12 ft. long. They are served by two overhead chargers, one of 15 tons and one of 5 tons capacity.

Leading from the reheating furnace bay are three bays, the first two of which contain the 10-ft. plate mill and the third the 7-ft. plate mill. The 10-ft. mill receiving rack extends into

the reheating furnace bay and receives the slabs direct from the charger. A rope-driven chariot receives slabs from the charger and conveys them to the receiving rack of the 7-ft. mill.

10-ft. Plate Mill.—The 10-ft. mill has two stands with soft rolls 42 in. in diam. and 12 ft. long, and hard rolls 42 in. in diam. by 10 ft. long. The rolls are driven by a reversing motor, which

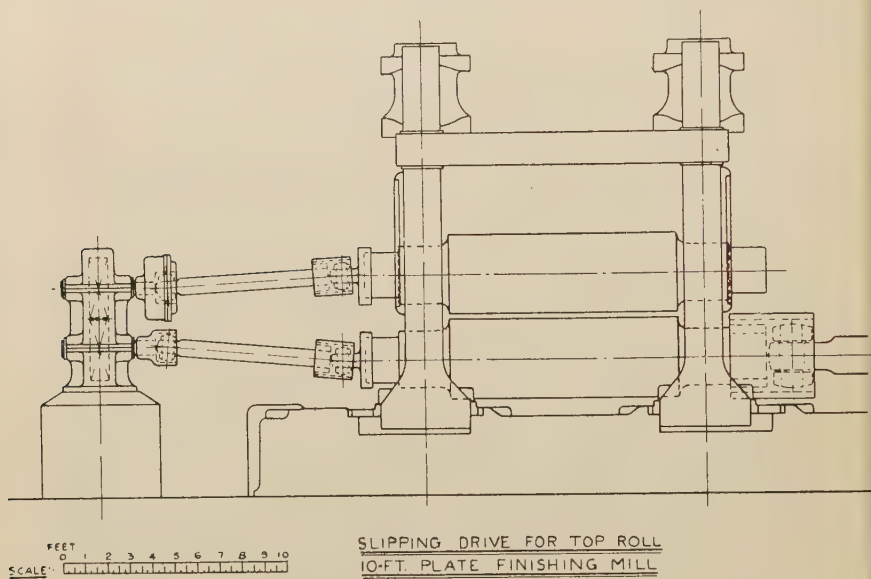


FIG. 10.

is a duplicate of the slabbing-mill motor. The top hard roll is driven from the bottom roll by light gearing and a slipping clutch, as shown in Fig. 10, to enable the top roll to be balanced by a hydraulic cylinder. A turnover gear for the slabs is provided between the two stands. On the front of the roughing stand a hydraulic slab turning stool is fitted. Both stands are provided with hydraulic centring arms on each side of the rolls.

The mill scale at this mill and also at the 7-ft. plate mill is dealt with in a similar manner to that at the slabbing mill.

The finished plates are passed through a plate mangle on to the receiving side of the cooling bank. The mangle has nine rolls 18 in. in diam. by 12 ft. 6 in. long, and is of specially massive

design. The cooling bank is 115 ft. long and 95 ft. wide, and has two sets of chain conveyor type skids, each set being divided into three sections. The skids are arranged so that all the plates on one or more sections are moved towards the delivery rack at one operation. Inserted between these skids are two hydraulic turnover gears for plate inspection. Over the mill stands a 40-ton overhead crane is provided. From the cooling bank delivery rack the plates are passed on for shearing.

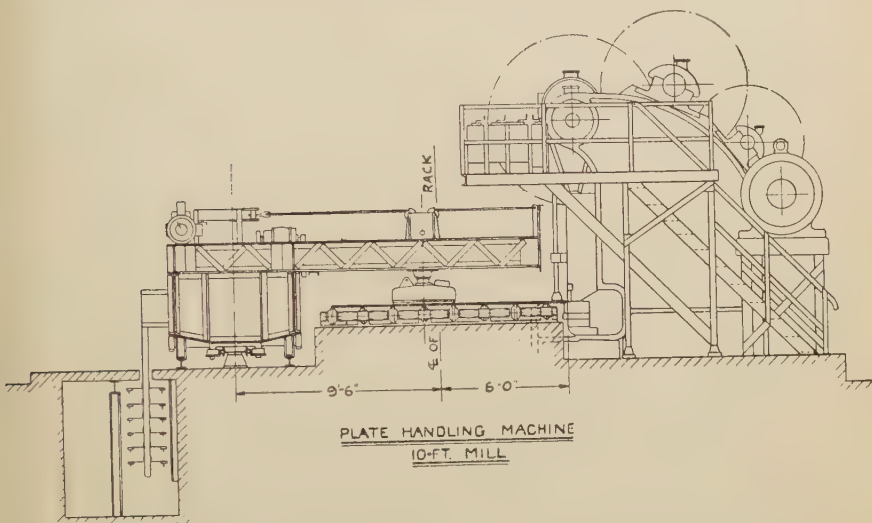


FIG. 11.

The shearing equipment consists of two side-cutting electrically operated and one cross-cutting hydraulically operated shears. In front of each side-cutting shears are two magnet plate-handling machines of original design (Fig. 11) to manipulate the plate for shearing on a dead roller bed, which is a continuation of the cooling bank delivery rack. The side-cutting is done first, and the plates are then passed through the cross-cutting shears.

After passing through the cross-cut shears the plates pass along a rack on which are three throw-off tables, where the rectangular plates, being finished, are thrown off on to the floor to be sorted out, and loaded by magnet cranes.

Plates to be cut to sketches pass over the above-mentioned

rack and over a chain conveyor into a cross bay which is common to both mills. In this bay are two hydraulically operated sketch shears surrounded with castors, and so arranged that plates from either mill can be easily brought to either shears. The bay is served by a 15-ton overhead crane with a magnet beam.

7-ft. Plate Mill.—The 7-ft. plate mill is a one-stand two-high reversing mill with rolls 32 in. in diam. and 7 ft. long. The rolls are driven by a reversing motor, capable of exerting a maximum torque of 14,000,000 in.-lb. up to 60 r.p.m., which has a maximum rating of 13,500 H.P. from 60 r.p.m. to 120 r.p.m. The slabs are fed on to the receiving rack by chariot from the reheating furnace bay. On each side of the rolls are fitted hydraulically operated centring arms. The finished plate is passed through a plate mangle having nine rolls 14 in. in diam. by 7 ft. 6 in. long.

The plates are then passed over either of two sections of the cooling bank by ordinary rope-driven skids on to a parallel rack, then back over a third section of cooling bank on to the original rack, and so on to the shears. Each section of cooling bank is 60 ft. long by 47 ft. wide. Built into the third section is a plate turnover gear. The shearing equipment is similar to the 10-ft. mill, but with smaller and faster shears and also with faster plate-handling machines. This shearing bay is served by two overhead cranes, both fitted with magnet beams and magnets.

An annealing furnace to take plates 50 ft. 0 in. by 6 ft. 6 in. is in course of construction. This will be heated by blast-furnace gas. A mangle for flattening thin plates when cold is also under construction.

Electric Power Sub-Station.—The driving motors of the two plate mills are placed in the same portion of the centre bay of the mill bays. This portion is specially closed in and forms the main electrical sub-station of the steelworks, besides housing the main mill motors. Here terminate the main cables from the power house. The sub-station also contains two motor-generator flywheel sets, three motor-converter sets, and two banks of static transformers. Each motor-generator flywheel set has one 3000 B.H.P., a.c. motor, and four d.c. generators each of 4500 B.H.P. maximum rating, and one flywheel of 36 tons weight. The a.c. motors are fed at the voltage generated, 6600 v., and the eight generators are coupled to the three mill motors in such a

way as to take advantage of the energy of both flywheel sets for any one of the mill motors. The three motor-converter sets are each of 750 kw. capacity and provide direct current at 220 v. for auxiliary mill and crane reversing motors. The static transformers provide alternating current for the continuous running motors throughout the steelworks plant. The lighting system is entirely separate from the power system and operates at a voltage of 110.

HYDRAULIC AND GENERAL WATER SUPPLY.

The hydraulic pressure water required at the open-hearth plant and at the mills is supplied by three centrifugal direct electrically driven pumps, each capable of delivering 600 gals. per minute at 750 lb. pressure when running at 2960 r.p.m. Two hydraulic accumulators are provided.

The main water supply for the works is obtained from the river Ancholme, and a pumping station with centrifugal pumps is built there, being about $4\frac{1}{4}$ miles distant from the steelworks. The pumps are capable of supplying 1500 gals. of water per min. As the water is of a hard nature, a water-softening plant is installed to treat the boiler water.

NOTES ON THE OPERATION OF THE PLANT.

From the inception of the plant it was decided to exploit the use of blast-furnace gas to the fullest possible extent, in order to reduce to a minimum the purchase of external fuel. Coke-oven gas not being available, it is not economically possible to save the coal necessary for open-hearth furnaces, nor is it expedient to save the coal used in locomotives. For all other purposes requiring fuel, blast-furnace gas is used. The total external fuel used at the steelworks is about 4 cwt. of coal per ton of ingots produced.

To secure the most efficient use of the blast-furnace gas the plant is well supplied with instruments. The gas is metered separately at each point of use, but not for each individual unit. The amount used is continuously recorded for blowing engines, power engines, boilers, stoves, reheating furnaces, soaking pits, and metal mixer.

Ironstone Mining.

The composition of the ore varies both in the different strata of the deposit and according to its position in the district, the variations being so considerable as to make it difficult for the blast-furnace manager to maintain a reasonably regular mixture in the furnace charge. To enable him to see at a glance the nature of the ironstone he has to deal with, sections are taken at distances of 50 to 100 yards apart in the various working faces, and a chart is made for each face showing sections with analyses. Movable pointers indicate the position at which diggers are working from day to day. A typical chart is shown in Fig. 12.

The cover is removed by an electrically operated chain bucket excavator. The ironstone is shattered by blasting, and is then loaded by steam diggers. For the blasting, liquid oxygen is now being used.

A typical analysis of a section of face is given in Table I. :

TABLE I.—*Analysis of a Section of Face.*

Quality.	Depth. Ft. In.	Moisture. %	Iron. %	Insoluble. %	Lime. %	Sulphur. %
Small pink . . .	0 9	10·8	28·8	24·9	1·0	0·092
Shelly pink . . .	1 3	7·7	29·7	22·3	2·4	0·082
Pink	2 4	6·9	23·2	20·4	11·1	0·122
Snap	2 0	4·7	20·3	14·6	14·1	3·230
Clay blue	1 1	7·1	19·8	33·8	5·2	0·287
Limy blue	2 9	4·9	28·2	9·0	9·0	0·542
Shelly blue	3 7	5·9	23·8	4·5	19·4	0·369
Limy blue	2 11	3·6	19·3	4·4	26·8	0·139
Soft blue	0 6	4·7	27·1	6·5	11·4	0·563
Limestone	0 10	2·6	16·8	3·4	26·4	0·349
Shelly pink	1 1	6·4	22·8	12·9	14·3	0·540
Pink	1 7	9·2	27·2	11·9	9·1	0·326
Limy pink	1 3	2·9	14·5	5·6	29·0	0·200
Pink	1 0	9·1	25·3	13·3	11·3	0·631
Grey	0 9	11·0	17·5	14·4	14·5	4·940
Pink	3 6	10·2	26·1	18·1	7·9	0·080
Total depth of face .	27 2	...	...	...	...	...
Average analysis	...	6·58	23·4	12·5	14·0	0·62

As will be seen from the analysis, the local stone has an excess of lime. Siliceous ores are added in the form of Northamptonshire

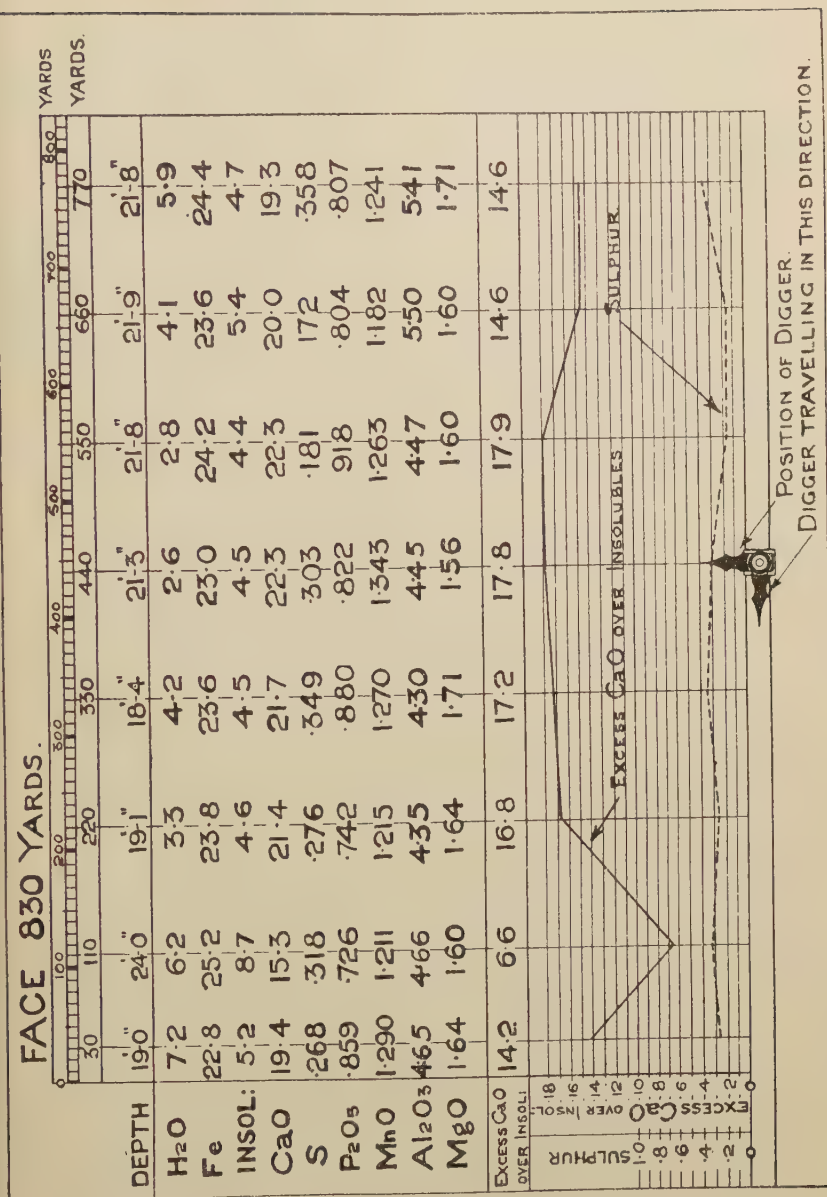


Fig. 12.

ore. Small quantities of foreign ores, flue, and tap cinder are also used.

The Northamptonshire ores are brought from mines leased and worked by the company at Colsterworth, near Grantham, Lincolnshire.

Blast-Furnaces.

The design adopted for the two new blast-furnaces was decided after experience with two mechanically charged furnaces, Nos. 4 and 1, at the Frodingham works. No. 4 was designed by an American consulting engineer, and was blown in in 1905. It was of the inclined skip-charged type, 85 ft. high, with lines as shown at *A* in Fig. 13A.

The results from this furnace were very disappointing. The distribution of the burden was bad and the make of dust was excessive, being as high as 7 to 8 per cent. of the ore burden.

To get over the distribution difficulty a new furnace top was designed by the Frodingham staff. This was of the revolving small bell type, as shown in Fig. 14, and was put into operation in 1906 ; it is still in use as originally made. As far as is known, this was the first furnace to be fitted with a revolving top of this type, and, as will be seen from the drawing, it is very similar to that known as the McKee top now so much used in America. The furnace worked much better with the revolving top, and the output increased from 900 to 1100 tons per week, but the dust trouble still continued. When the furnace was relined this was reduced by increasing the diameter of the stock line.

The second furnace, No. 1, was blown in in 1912-13. About this time the bucket system of charging was much in favour in Germany, the advantage claimed for this system being a saving in the number of drops of the coke. The coke used at that time was soft, and this system was considered to be an improvement on skip charging. As, however, it was convenient to make use of the storage bins and transfer cars already installed for the skip-charging furnace, a compromise was adopted and a vertical horizontal bucket type of charging system was used. The height of this furnace was 80 ft., and the results of working were about the same as No. 4.

No. 4 furnace was again relined, as shown at *B* in Fig. 13A,

in 1922, and is still working. The coke is screened at the furnace through $1\frac{1}{4}$ -in. screens. The results of working on this furnace show some improvements, but in view of later experience with No. 1 furnace they are not good.

No. 1 furnace was next relined with lines as shown at *C*, Fig. 13B. The coke is also screened at this furnace. The results of this furnace are the best that have been obtained in the Lincolnshire district. It gave an average output of 1750 tons per week, with a coke consumption of 27 cwt. of South Yorkshire coke and a burden of 75 cwt. per ton of pig iron, and a dust production of 1 to $1\frac{1}{4}$ per cent. of the ore burden. In all the above-described experiences the ore was broken down to 6 in.

A make of 250 tons per day may perhaps appear small, but with a burden of 75 cwt. per ton of pig, and on the basis of coke burned only, without taking into consideration the large volume occupied by the ore, it is equivalent to an output of over 400 tons per day in a furnace working on rich ores such as are used in Germany and the United States, where large outputs are recorded.

In view of these results the new Appleby furnace No. 5 was made on exactly the same lines. With further experience of this furnace it has been decided to increase the hearth diameter in building No. 6 furnace, the lines of which are shown at *D* in Fig. 13B.

Stoves.—The stoves are built with an outside layer in the lining of special non-conducting bricks $2\frac{1}{2}$ in. thick, with the $1\frac{1}{2}$ -in. space between the bricks and casing filled with non-conducting powder.

It was intended to make the checker work with 4-in. square openings, but when the time came to line the stoves, experience of cleaning plants of the steel mattress type at other works was available, and as it was not good the openings were made 6 in. square. This decision has been fully justified.

The burners originally intended for these stoves were of the ordinary pull-back type. Before they came to be fitted some improvements had been made on this type at the Frodingham works. No. 1 furnace had three stoves working on dirty gas. An increase in the output of this furnace had been attained, so that when a stove was "off" for cleaning the furnace was short of heating capacity. An additional stove was apparently required.

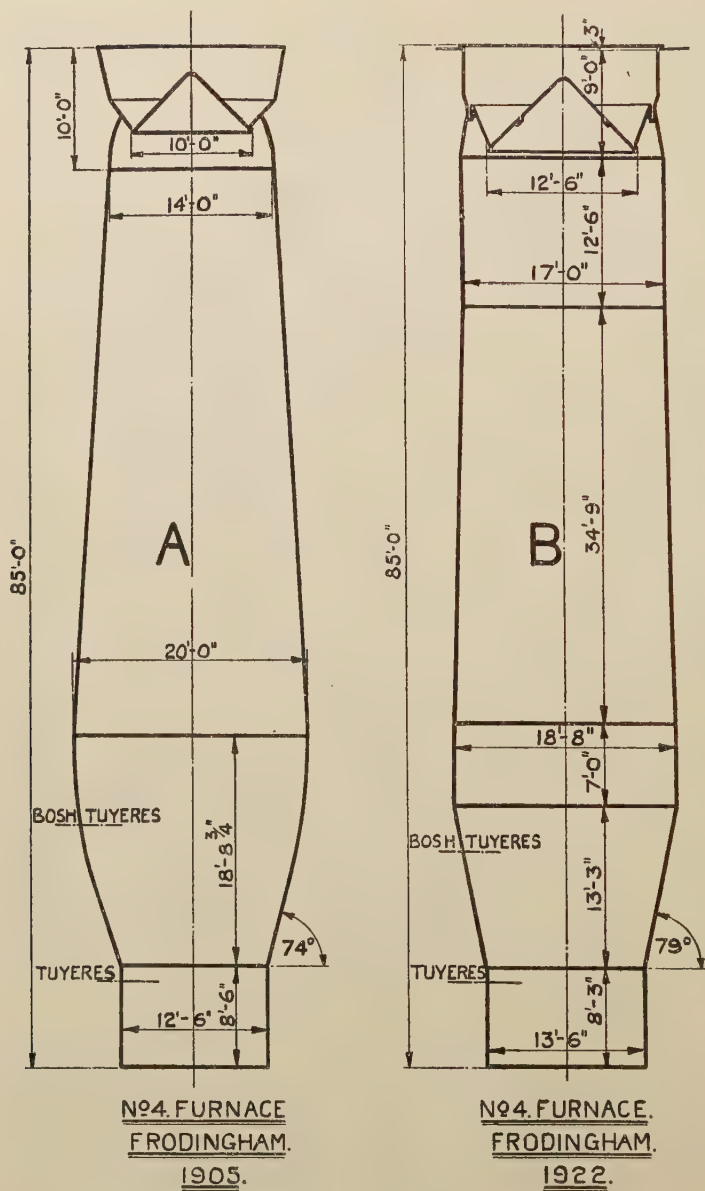
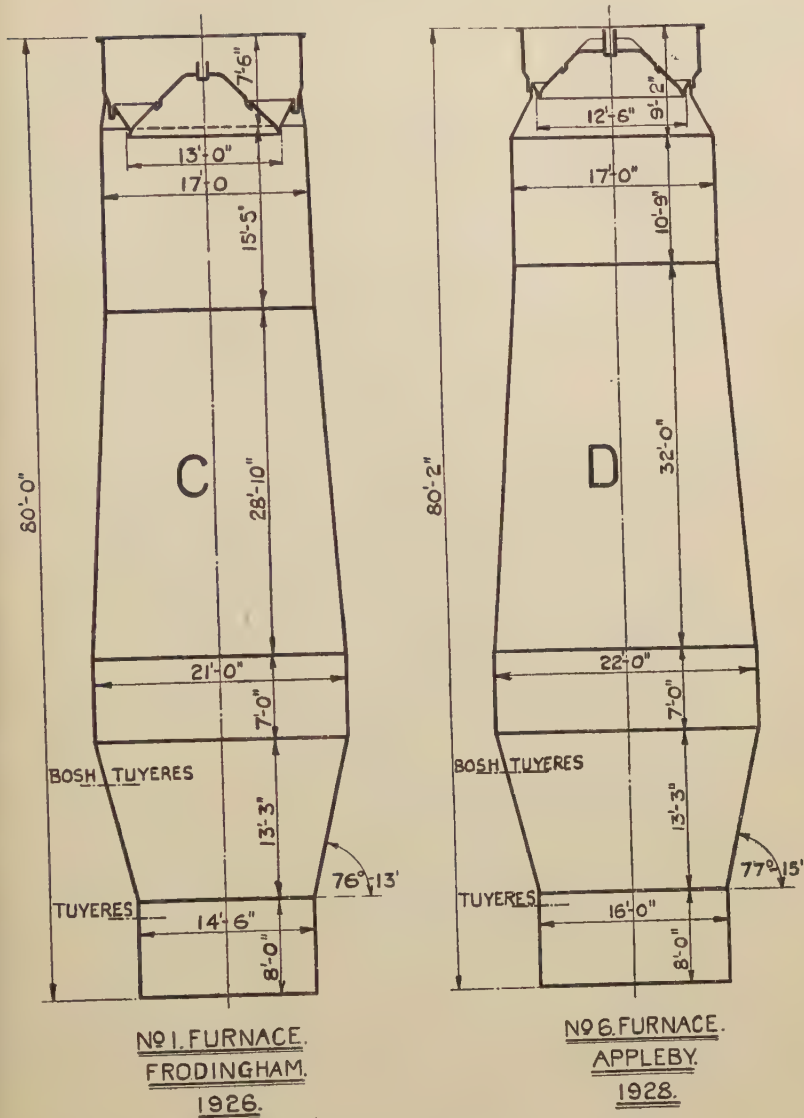


FIG. 13A.—Furnace Lines.



Instead of building this, however, two stoves were fitted with special burners, in which the air is supplied under pressure and automatically regulated.

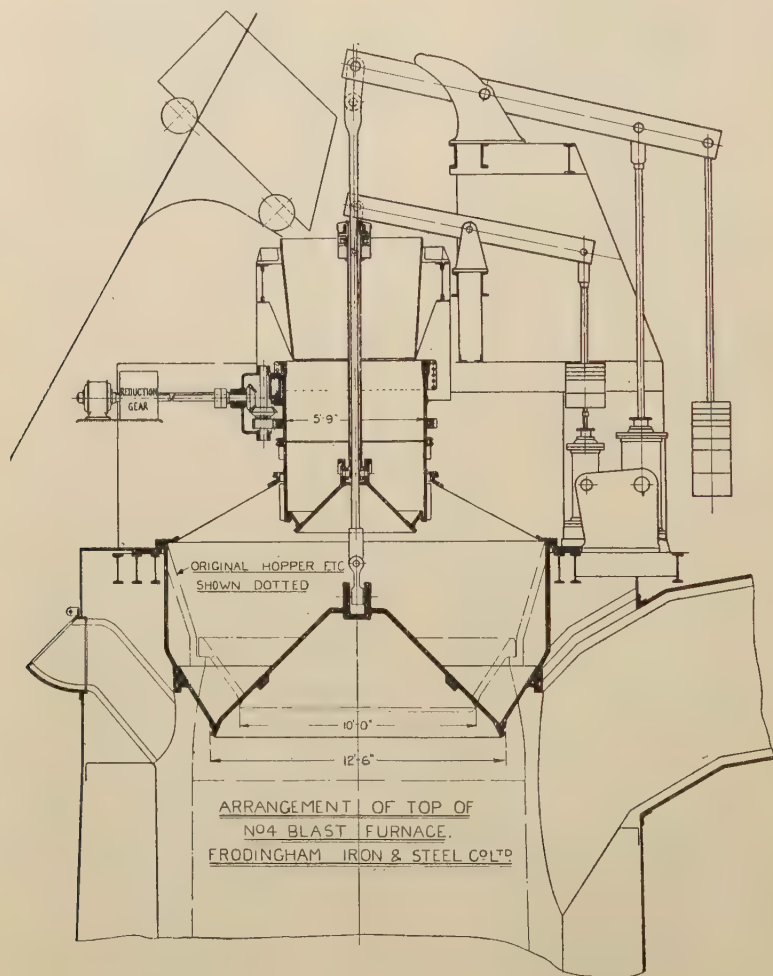


FIG. 14.

The aim of these burners is to get a large quantity of gas into the stoves per unit of time, and to ensure sufficient air to burn it. After a successful experience with these burners it was decided

to attempt to achieve the same result using air induced by the stove draught on the third stove. A larger gas opening was made on the stove casing, and a burner, as shown in Fig. 15, was fitted. It was found that this stove could be heated up quickly enough to enable it to take its place alternately with one of the other stoves. CO_2 and CO indicators and recorders were fitted, and these showed results for the three stoves which were nearly identical. The special burners on the first two stoves had the

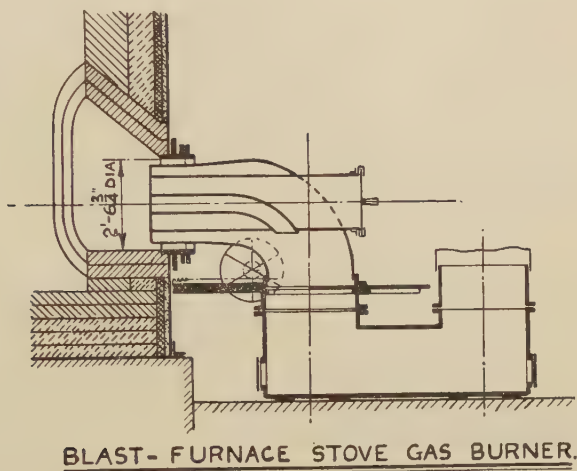


FIG. 15.

advantage of being automatic in operation, whilst the stove minder in the other case had to regulate the air in order to get the CO_2 as high as possible without the indicator showing CO .

Ore-Crushing Plant.—The decision to install an ore crusher of adequate size calls for no comment. It is generally accepted that preparation of the ore by crushing gives improved results. Experience at these works has shown that an increase of 10 to 12 per cent. in the output and a decrease of 3 per cent. of the coke consumption is obtained with ores broken down to 5 in. as compared with the lumpy stone direct from the mines, and in addition the quality of the iron is improved.

The adoption of a jaw type crusher for the main crusher was due to the very large lumps of ironstone which have to be dealt

with. Experience with this type, however, has shown that during wet weather the fines and softer stone clog at the crusher. To avoid this a preliminary grading screen of very massive design, having cast steel segments with 6-in. openings, was placed in front of the crusher. The fine stone, therefore, does not pass through it. This plant has been laid out so that a ropeway system may be added to convey the crushed stone to the ore bins and kilns.

Coke Screening.—The coke-screening plant has proved effective. The screened coke is graded, the nuts finding a ready sale for domestic purposes and the fines being used as fuel for calcining kilns.

Blowing and Power Plant.—The adoption of gas engines for blowing also calls for no comment. The adoption of gas engines for power purposes is perhaps not such a clear case, but the argument for this is too lengthy to enter on here. In weighing the respective advantages of gas alternators and steam turbo-alternators local conditions must be studied, especially the water question, which in this case required serious consideration.

The switch gear has been arranged so that in the event of a super-power station being operated in this district, it would be possible for the plant to feed into the grid. The plant is operated so as to maintain a fairly uniform load on the gas engines, the variations being taken by the steam set.

The gas engines have the advantage of being fed with very clean gas. The gas from the Halberg-Beth dry cleaning plant, after passing through a cooling tower, has a dust content of 0.002 to 0.005 grm. per cu. m., and it has been found possible to run engines on this for two years without having to clean the inlet valves. On similar engines with wet cleaning down to 0.02 grm. per cu. m. the inlet valves are cleaned every three months.

Fine Gas Cleaning.—The Halberg-Beth cleaning plant is well known and needs no further description. In this case the gas is pre-cooled by passing through vertical steel towers with internal air-cooling pipes. The connections to and from these towers should have better provision for dust removal. The cleaning plant itself should be of more robust construction. After working for some time the chambers cease to be absolutely gas-tight, due no doubt to expansion and contraction. Great care has to be

taken when starting up the plant after a shut down, as the gas-house becomes untenable if any appreciable time elapses between putting the gas through the plant and starting the fans. The third and fourth units of this plant, which were put into operation early in 1928, have an improved method of

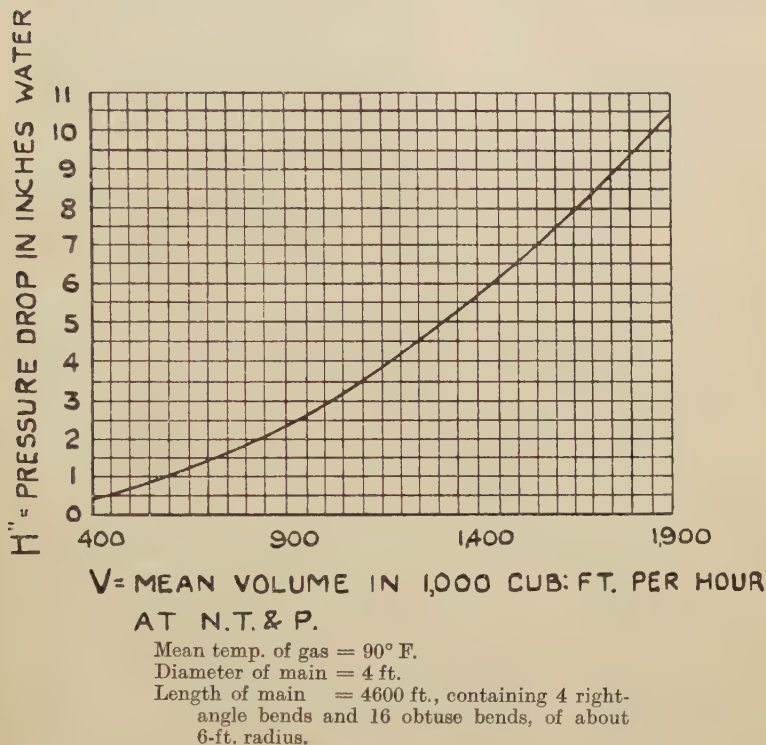


FIG. 16.

bag-shaking and valve-operating gear, introduced for the first time in this country. This is done by compressed air cylinders controlled as to period and length of operation by an ingenious timing valve. This so far appears to be a distinct improvement on the previous method of shaking.

The gas delivered to the steelworks is boosted up in pressure by two fans, each capable of dealing with the maximum quantity available— $1\frac{3}{4}$ million cu. ft. per hour—and raising its pressure

12 in. It may be of interest to record the drop in pressure through this long length of piping. The pipe is 4 ft. in diam., and is of ordinary mild steel riveted construction. The length between the points of observation, the number and nature of the bends, and the drop in pressure for various quantities, are shown in Fig. 16.

The method adopted to ensure a continuous supply of power and gas to the steelworks is as follows. After leaving the cleaning plant the gas piping is arranged to supply gas to the gas engines, to the steelworks, and to the boilers and stoves, in that order. An automatic valve is placed between each of these points, which keeps the pressure uniform at 4 in. for gas engines and $3\frac{1}{2}$ in. for steelworks boosters, and allows the remainder to pass to the boilers and stoves. This takes care of the ordinary stoppages for casting.

The Working of the Open-Hearth Plant.

Size of Furnaces.—The original scheme for the plant consisted of three tilting furnaces of 250 tons nominal capacity, this size having been decided upon from the experience of the tilting furnaces at the Frodingham works, where was built the first tilting furnace in this country of 100 tons capacity. Three further furnaces had been installed at Frodingham, each of larger capacity, the fourth being 160 tons, the largest size that could be put into an existing building. The results from these furnaces showed an improvement in economy in favour of the larger furnaces. It was decided, thereupon, to build the Appleby furnaces of 250 tons capacity, which was slightly larger than anything of this type that had been built at that time (early 1914). Later, in 1925, when it was decided to add a fourth furnace to the scheme, further consideration was given to the size of the furnace, and the size was increased to 300 tons.

Up to the present only two of the 250-ton furnaces and the 500-ton mixer have been in use, and their working has been somewhat erratic owing to the very varying demands of the plate mills.

Mixer.—The mixer is 53 ft. 8 in. over chills, with a bath 48 ft. by 18 ft. by 6 ft. 6 in., and is heated by blast-furnace gas. It is of the semi-active type. The working bottom is made by ramming crushed burnt dolomite and tar over magnesite bricks, and

burning it in. The molten pig iron is brought to the steelworks from the blast-furnaces in 30-ton ladles, and is poured into the mixer by the casting bay cranes. The mixer iron is taken out at the opposite side—the furnace charging bay. The slag runs off into ladles in the casting bay. No considerable amount of refining is done in the mixer, the aim being to lower the silicon and sulphur to some extent without losing phosphorus and too much manganese, and to supply a good standard iron to the furnaces. The additions to the mixer are principally local basic ironstone containing as received—

	%
Iron	18 to 22
Lime	20 to 25
Silica	3 to 6
Manganese	1

Sufficient mill scale or limestone is added to keep the slag in a suitable condition. The amounts used over a 6-months period are :

Mill scale	0.15 cwt. per ton of iron
Limestone	0.10 „ „ „
Basic ironstone	0.60 „ „ „

The slag, amounting to 0.60 cwt. per ton of iron, is returned to the blast-furnaces.

The analysis of iron from the mixer taken over the last 6 months of 1927 is as follows :

Si.	S.	P.	Mn.
0.28	0.057	1.31	0.99 per cent.

The mixer consumes about 225,000 cu. ft. of blast-furnace gas per hour.

Tilting Furnaces.—The principal dimensions of the 250-ton furnaces are :

Length of body over chills	55 ft.
Size of bath (at greatest length, &c.)	45 ft. × 13 ft. × 3 ft. 6 in. average depth
Checker work, air regenerators	19 ft. 6 in. × 11 ft. 8 in. × 15 ft.
„ „ gas „ „	19 ft. 6 in. × 7 ft. 4 in. × 15 ft.
Air port	18.6 sq. ft.
Gas port	3.7 „

The furnaces are heated by producer-gas. They are kept hot on Saturday afternoon by means of blast-furnace gas whilst burning out the producer mains. The air is supplied by a fan,

and the waste gases pass through a water-tube boiler on their way to the chimney. The working bottom is made by ramming crushed burnt dolomite and tar over magnesite bricks and burning it in.

The producers gasify 25 cwt. per hour each of 1 to $1\frac{1}{2}$ in. Yorkshire gas nuts, and make excellent gas of the following composition :

<i>Dry Gas.</i>						Per cent. by Volume.
CO ₂	.	.	.	.	.	5.2
CO	.	.	.	.	.	25.0
H ₂	.	.	.	.	.	14.5
CH ₄	.	.	.	.	.	3.3
N ₂	.	.	.	.	.	52.0
Moisture	.	.	.	45 grm.	per cu. m.	

This is *an average of samples* taken over 6 months.

When tapping, about 230 tons of steel are taken out in three ladles in quick succession, and there is left about 20 to 40 tons of molten steel and about 10 tons of molten slag. On closing the taphole about 5 tons of limestone and 30 tons of mixer iron are charged. The slag-line is fettled with crushed burnt dolomite by means of a fettling machine, after which a suitable charge of limestone and oxides of iron is put in—say, 16 to 20 tons of limestone and 30 to 35 tons of oxides of iron. The cold iron and scrap available are charged on top of this at intervals as the charge melts down. During the intervals of charging, the linings of the furnace are fettled.

About 6 or 7 hours after tapping—when the charge is thoroughly hot—the main portion of the mixer iron is put in, causing a violent reaction. The charge is melted down thoroughly, during which period there is usually some loss of slag (3 or 4 tons), owing to the foaming of the slag. A further quantity of limestone and/or oxide of iron is added to the furnace as may be necessary ; the slag is run off when these additions are worked through.

The composition of the metal at this stage varies according to the composition of the steel required from carbon 1.0, phosphorus 0.08, sulphur 0.05, and manganese 0.50 per cent. to carbon 0.3, phosphorus 0.10, sulphur 0.05, and manganese 0.20 per cent.

A new slag is now formed and the bath kept strictly under

control and fed down carefully with limestone, burnt lime, and oxides of iron until of the composition required. The furnace is then tapped into three ladles of 75 to 85 tons capacity.

Owing to the necessity for casting three different qualities of steel from the same tap, it is often necessary partly to carbonise in the ladle, but it is quite possible to tap on the required carbon. This is done whenever the composition of the required steel allows it. The time taken from tap to tap varies from 17 to 20 hours normally.

Typical analyses of the bath when the charge is nearing completion are given :

Cast Analyses.

Time.	C. %	P. %	Mn. %	S. %		C. %	P. %	Mn. %	S. %
8.45	0.45	0.07	0.28	0.048	1st ladle .	0.21	0.027	0.70	0.035
10.5	0.24	0.06	...	...	2nd „ .	0.14	0.031	0.51	0.037
11.10	0.16	0.05	0.25	0.040	3rd „ .	0.13	0.033	0.49	0.036
11.35	0.15	0.04	...	...			

Tap, 11.45

The carbon and manganese differ in each ladle according to the quantities of carbon and ferro-manganese which are added.

Cast Analyses.

Time.	C. %	P. %	Mn. %	S. %		C. %	P. %	Mn. %	S. %
4.20	0.19	0.10	0.25	...	1st ladle .	0.08	0.020	0.34	0.035
5.30	0.12	0.05	...	0.045	2nd „ .	0.08	0.021	0.34	0.033
6.15	0.10	...	0.20	...	3rd „ .	0.07	0.021	0.32	0.033

Tap, 6.45

Cast Analyses.

Time.	C. %	P. %	Mn. %	S. %		C. %	P. %	Mn. %	S. %
12.10	0.80	0.07	...	...	1st ladle .	0.24	0.021	0.53	0.029
1.10	0.55	0.05	0.25	...	2nd „ .	0.22	0.025	0.50	0.029
1.50	0.40	0.05	...	0.034	3rd „ .	0.20	0.029	0.54	0.033
2.40	0.26	0.04	0.22	...					
3.10	0.24	...	...	...		

Tap, 3.20

The average output for six full working weeks with two furnaces working is—

K furnace, 2045 tons; maximum output, 2139 tons
L „ „ 2072 „ „ „ „ 2185 „

Owing to the condition of the order book since these works started, the supply of materials to the furnaces has been irregular. It has been necessary sometimes to use mixer iron only and no

scrap in the charge, and at other times much cold pig and scrap. Large tilting furnaces allow a very large variation of both quantity and quality of the materials charged without a correspondingly serious effect upon the quantity and quality of the product.

The figures given below are an average over a 6-months period :

Composition of Charge.

Steel scrap average . . .	18 per cent. ; variation, 7-26	%
Cold pig and iron scrap . . .	5 „ „ „	1-15
Mixer iron to make up.		

Iron oxides	15.0	%
Limestone	10.0	
Burnt lime	0.5	
Ferro-manganese	0.8	
Coal used at producers	15.7	
Slag made	16.0	

Composition of Basic Slag.

SiO ₂	10.3	%	P ₂ O ₅	16.44	%
Fe	10.1		Citric acid }	88.3	
CaO	43.4		solubility }		

The steel varies in composition from 0.06 to 0.35 per cent. carbon.

The size of the ingot varies from 6 tons to 20 tons, with or without hot tops—the usual size is 10 tons. The steel is poured through one 1½-in. fireclay nozzle, and the ingot may be cast from the top or the bottom.

The number of men employed is comparatively small. It has not yet been possible to obtain the full effect of the manning, as only two furnaces have so far been in operation at one time. On this basis over 40 tons of ingots have been made per man per week, the manning including all production workers, such as gas-producer men, loading men, furnacemen and mixer men, crane and charger drivers, ladlemen, teemers, and strippers.

This figure compares with 34 tons at the Frodingham Company's works, and 20 tons at works having fixed furnaces and using cold materials charged by machines.

Soaking Pits.—The ingots come to the soaking pits in about 230-ton lots at fairly long intervals, and as up to the present it has been possible to run the slabbing mill for only two eight-hour

shifts per day, the unheated Ggers pits which are installed have proved very useful.

The heated soakers are fired by blast-furnace gas, and although these are equipped for emergencies with a gas main from the open-hearth battery of producers, this gas has not been used.

The use of blast-furnace gas has proved quite successful, and when, as under the present trade conditions, continuous operation of the mill is not possible, the losses due to lighting up producers, and also the burning out of producer-gas mains at week-ends, are saved.

Furnaces built for using exclusively clean blast-furnace gas must have the gas flues and regenerator chambers very carefully built. The ordinary brickwork is liable to pass gas, especially when a furnace is put into operation after having been cooled down.

Rolling Mills.

The ingots are placed directly on to the slabbing-mill approach table by the soaking crane, and no tilting chair is provided. A simple hydraulic buffer is placed between the two end rollers to prevent undue shock on the rollers. This arrangement works quite well and saves a piece of mechanism which costs a lot for upkeep.

The mill crew consists of four men—two for operating the mill, one for greasing, and one for operating the slab shears. Usually three men are required for operating such a mill, one of whom operates only the mill drive. By the introduction of a relay system for reversing the mill, in which the operator has simply a small handle to operate, it has been found possible for him also to work the manipulator. The other man operates the screw-down and the mill roller tables.

The slabbing mill works well, the drive, spindles, and mill train generally being very free from jar or noise. The manipulators are of the universal type. All motions are electrically driven, and have already been described and illustrated by Mr. T. W. Hand.¹ In this type, in order to facilitate slabs entering the edging holes, the rack rollers are reduced in diameter at each

¹ *Journal of the Iron and Steel Institute*, 1925, No. I. p. 43.

end. Excessive and unnecessary strain is put on the guide plates and rollers when heavy slabs are moved across the rack. This defect could be eliminated by the use of collars on the rolls, so that the rack rollers could be made plain, or it could be lessened by having a more gradual taper on the rack rollers from the smaller to the larger diameter, as shown in Fig. 17. A further improvement would be to reduce the height, and so the centre of gravity, of the guide plates.

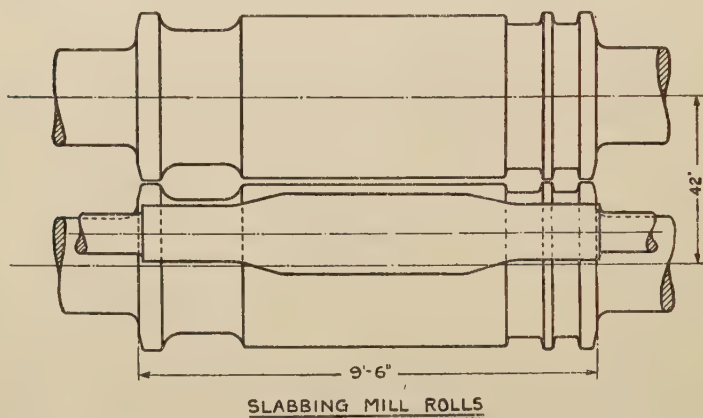


FIG. 17.

The slab shears, which are of the upcutting type, have proved highly satisfactory.

Reheating Furnaces.—The reheating furnaces are similar to the soakers but shallower. They have sliding roof doors and are fired exclusively with blast-furnace gas. The deciding factor in adopting this type of furnace was the weight of the largest slab to be handled, namely, 15 tons. A charging machine of the overhead and overhung type necessary for horizontal furnaces is a very cumbrous affair, and reheating furnaces of the vertical type having apparently proved satisfactory in other works, the vertical type was adopted.

From experience with this type of furnace, however, it is doubtful whether it is the most suitable for the smaller and lighter slabs required by a light mill. The large opening made in the

roof, tending to cool the slabs, and the difficulty for the charger driver to see down into the furnace, are certainly objections.

10-ft. Plate Mill.—The 10-ft. plate mill, which is reversing with two stands, was completed some time before the 7-ft. mill. In order to deal with mixed specifications, it has been called on to roll a large range of thicknesses and areas. Plates $\frac{1}{8}$ in. thick, 5 ft. wide, and 60 ft. long, also $\frac{1}{4}$ in. thick, 8 ft. wide, and 100 ft. long, have been successfully rolled. This is obviously undesirable, and is only mentioned to indicate the great elasticity of the mill. The heaviest plate rolled so far was $132\frac{1}{2}$ in. wide, $1\frac{5}{16}$ in. thick, 32 ft. 3 in. long, finished sizes, and weighed 8.9 tons.

Owing to the fact that the hard rolls are ground so that an exact camber can be relied upon, wide thin plates can be rolled to a uniform thickness. Further, adjusters by which the slab is kept in the centre of the rolls having been installed, plates of exceptional lengths can be rolled and kept straight. The hard rolls are both driven, the top roll being driven from the bottom roll through spindles and a light pinion drive, and the top spindle having a slipping clutch, as shown in Fig. 10. This has proved very successful and is undoubtedly a great improvement, for when both rolls are positively driven they require to be kept in pairs of nearly the same diameter. Also when the top roll is not driven it cannot be balanced, and there is a barbarous shock to the bearings, housings, &c., when the plate enters the rolls. The output of this mill can only be estimated so far, as it has not been possible to give it a run on plates which might be considered suitable for a mill of such a size. The best performance has been on a run of $\frac{5}{8}$ -in. plates, when 360 tons were rolled in $6\frac{1}{2}$ hours.

Shearing Equipment.—In the shearing equipment the large number of workers at one time employed have been replaced by mechanical means. The system adopted, which was designed before the rotary side-trimming shear was known in this country, is in one respect similar to the latter in principle—namely, the plates as rolled are sheared on the sides before cutting into lengths at the cross-cut shears. All other systems, both hand and mechanical, reverse this order.

The former system, owing to the fact that it takes each plate marked off at one bite instead of having to nibble at it in pieces, would appear to be obviously faster. The experience gained so

far shows that with plates $\frac{1}{4}$ in. thick and over the shearing can keep up with the mill. As an example, in the case of the above-mentioned 360 tons in $6\frac{1}{2}$ hours a minor break-down took place on a plate-handling machine, in consequence of which plates were lifted off the racks so that the cooling bank should not be blocked. The necessary repair was made in 30 minutes, and afterwards the plates on the floor were sandwiched back on to the rack and the shearing overtook the make of the mill. All these plates were rectangular, and they were sheared ready for despatch by three men, excluding scrappers.

One operator only is required at each side-cutting shear, and he is stationed on a platform looking down on the shear blade. The two plate-handling machines run on a track which has a central guide rail parallel to the shear blade. On each a jib carrying a magnet extends across the dead roller table which is between the track and the shears. The magnets have a vertical and cross travel movement. All the motions are controlled by the operator from his platform by remote control. A plate having come from the cooling bank rack, the operator fixes one magnet to each end of the plate and moves it under and in line with the shear blade. A press button automatically brings into operation the hydraulic clamps and sets the blade in motion. The shears are fitted with right-angle end blades, so that each cut separates the scrap. After the first cut the plate is travelled parallel with the shears for succeeding cuts, requiring little or no further lateral adjustment. One side having been sheared, the plate is passed along to another pair of plate handlers with a shear of the opposite hand, and thence through the cross-cut shears.

Experience with this system shows that with long plates the shears cut straighter than it is possible to mark the plates with the present method of marking. Some form of mechanical marker, or in the case of rectangular plates a system where no marking is required, seems to be called for.

7-ft. Plate Mill.—Little can be said yet of the 7-ft. mill, which has only been in operation a few weeks. Provision is made in the layout for adding a further stand of rolls, making it then a tandem mill.

It has been found possible to roll plates as thin as 13 gauge or 0.092 in., and by substituting larger rolls it is hoped to roll still

thinner gauges. The shearing equipment has shown that it can easily keep up with the mill make even on thin plates.

In conclusion, it is hoped that a study of the equipment of the above works will help somewhat to refute the reproach so often cast at British works—namely, that to see really modern works one must travel abroad. It is unfortunate that the present state of trade prevents its full operation, but it is confidently believed that, given better trade conditions, the plant will fully justify its existence and bring some credit to this district and country.

Thanks are due to the various members of the works staff who have assisted in preparing this paper.

DISCUSSION.

Mr. C. M. SCHWAB (New York) (Hon. Vice-President) said there was very little for him to say on the subject. He often wondered how people managed to design plants in this country with the small output compared with the great American output. He did not feel that America deserved the credit it was given. Taking a mill that ran 365 days of the year on one size of rods or sheets, if it were not possible to get good costs under those conditions for all that was produced they would be pretty bad engineers. The outstanding practice, which seemed to him to be the coming thing in America, was first of all very large blast-furnaces, which were now being planned for a minimum of 800 tons of pig iron a day, and usually about 1000 tons of pig iron were obtained; as a result of that they had been able to cut their direct labour costs on blast-furnaces 35 per cent. or more. The next great improvement that had been made was in the size of their open-hearth furnaces; they were now making them very much larger than ever before, up to 250- and 300-ton heats, dividing the heats in the ladle and getting very great economies. The chief change in the years to come would be the continuous rolling of sheets. They had continuous mills to break them down to a practicable and finished size, and had been able to show an economy of about £2 per ton in the cost of producing sheets. Those were the three outstanding features of American mill practice to-day—big blast-furnaces, large open-hearths, and the continuous rolling of sheets.

He had had a cable from America that morning and had found that the mills were running 90 per cent. full, and the only thing that they had to look out for now was to get that extra 10 per cent. America was very poor, not making much money, and they were ashamed to say that with their vast investments of something like six thousand million dollars they were not making much over 5 per cent. on their invested capital. In the steel industry to-day, after 50 years of observation, he thought the thing was not the perfecting of their costs in the manufacture of steel, but the perfection of their method of distributing their steel so as to get a better price. The chief line on which it would be possible to make a better return in America would be some method of selling the steel by which they would be first of all protected in their home markets for the chief consumption, and secondly distribute what they had to distribute in some manner collectively that would comply with the law and give them the advantage of selling at a price which would give a profit on the capital invested. Those, he thought, were the things to which they must devote themselves in America as well as in this country. While it was exceedingly interesting to listen to technical discussions, his mind was constantly running on the matter of where they were going to get a better price for the steel.

Professor HENRY LOUIS (Vice-President) remarked that on p. 186 the authors mentioned that liquid oxygen was now being used for blasting. He was particularly interested in that matter, because he believed he was the first person to attempt to use liquid oxygen for the blasting of ironstone in this country. He had obtained technically satisfactory results, but the economic results were not satisfactory. He recollected that the Cleveland Mine Owners' Association had had a series of experiments tried with liquid oxygen, and that they also came to the conclusion that the method presented no economic advantages. On the other hand, he had seen liquid oxygen used successfully in the iron ore mines of Lorraine. Apparently it was of use in Lincolnshire, and he would be grateful if the authors would give a few more details, especially with regard to the economic results.

CORRESPONDENCE.

Mr. T. W. HAND (Sheffield) wrote that the authors were to be congratulated on having so effectively condensed into a single paper some reference to practically all the vital factors comprised in the many processes involved in the manufacture of steel plate, from mining the ore to the despatch of the finished product.

He (Mr. Hand) had been privileged to see the Appleby plant many times, and was impressed with its possibilities both as regards manufacturing capacity and economical operation. In the latter aspect, it was noteworthy that this was probably the first full combination of the use of blast-furnace gas for the generation of power together with the electrical operation of all works machinery yet realised in the United Kingdom.

The authors had referred in particular to the system of plate shearing in use at these works. Although not limited, the system described appeared to be particularly devised for dealing with long plates, and it would be interesting to know whether economies in regard to power consumption at the mill, shearing costs, and yield of saleable product had already been realised.

In their concluding paragraph the authors made some reference to comparative equipment of British and foreign steelworks plant. It seemed to him (Mr. Hand), particularly after perusing the paper, that so far as plate manufacture was concerned, this country was, if anything, ahead of competitors. On the other hand, it appeared rather significant that most of the entirely new works laid down during the last 10 years were devoted exclusively to the production of plates, and many equally modern plate mills had also been installed in existing works. Although not exactly within the scope of the present paper, possibly the authors

would state whether their concluding remarks were to be considered in a general sense as applying to the manufacture of all classes of rolled products.

The Authors replied that they were interested to hear Mr. Schwab's remarks about practice in America. Although they had not in this plant reached blast-furnaces making 800 to 1000 tons per day—partly on account of the low-grade ore which they were using—they had, on the other hand, described, and were using, steel furnaces of 250 to 300 tons capacity, which size, it appeared, America was only now beginning to adopt.

Referring to Professor Louis' remarks on liquid oxygen explosive, they had been using that explosive for the last six months for getting Frodingham ironstone; they were very satisfied with it, and found it safe and efficient. They had not yet a plant for the production of liquid oxygen at Frodingham, consequently they had to bring it from Sheffield by motor lorry daily, or on alternate days, as required in the mines. Under these conditions, they had reduced the cost of explosive by over 30 per cent. as compared with high explosives previously used. They estimated that they would save fully 50 per cent. if they manufactured their own liquid oxygen.

With regard to Mr. Hand's remarks, they had not had an opportunity of comparing their shearing costs with other systems, but were satisfied that they had obtained considerable economies over hand-shearing.

With reference to the yield of saleable products, they were of the opinion that there should be little difference between the various methods of shearing.

The concluding remarks were made in a general sense.

BLAST-FURNACE PRACTICE IN NATAL.¹

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(NEWCASTLE, NATAL).

INTRODUCTION.

THIS paper concerns principally the blast-furnace plant situated at Newcastle, Natal, owned by the Union Steel Corporation (of S.A.), Ltd., of which the authors are manager and chief chemist respectively. Its object is to describe briefly the development and pioneering difficulties connected with the pig iron industry in South Africa, followed by observations on the character and distribution of raw materials in the Province of Natal and the actual working results of operation over a period of about 15½ months.

As there is only one iron blast-furnace in the whole continent of Africa at the present time, it is interesting to review the main events which have led up to the commercial production of pig iron in South Africa, where the white population does not exceed the combined populations of Manchester and Birmingham. It will be apparent that outputs of iron and steel must, in the first stage, be modest, and then progress as subsidiary industries are established.

The Union Steel Corporation commenced operations in 1913 at Vereeniging, Transvaal, for the manufacture of steel products from ingots made from smelted steel scrap. For several years previously the railways and mines had been inconvenienced by the enormous accumulations of steel scrap, the exportation of which did not pay on account of the long distances to the coast. After long negotiations with many parties, an agreement was entered into for a period of 16 years, whereby the railways supplied their scrap at a low price to the new company, which in its turn was guaranteed the orders for such steel products as the Corporation could produce, with due consideration to quality and time of delivery. Owing to difficulties in obtaining new plant, &c., during

¹ Received January 31, 1928.

the war period, it was several years before the Vereeniging Steelworks were established on a paying basis, but eventually a regular and substantial tonnage of rails, bars, sections, and steel castings was forthcoming, and was quickly absorbed by the railways and mines.

In recent years, however, the supply of suitable scrap has become progressively less than the consumption, and it became obvious that a sound steel industry could not be expanded on a scrap basis only. The manufacture of pig iron on a commercial scale thus became an essential factor. In the meantime, a blast-furnace plant was under construction at Newcastle by a new company called the Newcastle Iron and Steel Company. Owing to lack of capital the plant could not be finished, and arrangements were made to absorb this company into the Union Steel Corporation, thus consolidating the iron and steel interests to the mutual benefit of both companies.

For the pioneer work of laying the foundation of the pig iron industry in Natal great credit is due to Mr. J. K. Eaton, who sank a large amount of his private capital in the original Newcastle concern, as he was convinced that the natural resources of Natal would assure the future prosperity of the industry. He chose Newcastle as the site for the plant on account of its excellent water supply ; the carriage on the ore and coke to that town was slightly higher than to the ideal geographical centre of the ore and coking coal deposits about 40 miles away, but ample water facilities did not appear to exist at the latter place.

Under the direction of Mr. A. K. Reese, consulting engineer to the Corporation, the plant was thoroughly overhauled. Necessary additions were made in the way of improved boiler and water service equipment, &c., while the hearth and bosh of the furnace were enlarged and redesigned on more modern lines. Many other details required serious attention, and after an organisation for operation was secured and trained, the furnace was blown in by Mr. Reese on June 18, 1926. The primary object of production was, of course, to supply the necessary basic pig iron for replacing at least 50 per cent. of the scrap then being used in the open-hearth furnaces at the Vereeniging Steelworks. Foundry iron would supply the foundries of the Union, replacing the imported brands, and at a price to encourage the more extensive use of pig

iron, again in place of scrap, and so promote the more rapid extension of the engineering industries generally within the Union. To this end the Government had previously passed a Bounty Act to encourage the iron and steel industry in the country, whereby a substantial bounty was granted, decreasing in stages as the industry gradually became self-supporting. This was considered to be a better policy than imposing a tariff on imported iron or steel.

RAW MATERIALS.

Iron Ores of Northern Natal.

These ores occur in the Ecca series of the Karoo system, corresponding to the lower Permian rocks of Europe, and in which the coal measures are found.

This series is divided into three natural groups :

- (1 and 3) The upper and lower Ecca consist largely of black to blue fine sedimentary shales not less than 600 ft. in thickness.
- (2) The middle Ecca contains the coal measures and ore seams. It consists of sandstones, grits, and shales and is not less than 1250 ft. thick in the middle of the area. The rocks are nearly horizontal, undulating with a general dip SSW. Thin beds of calcareous sandstone are met with, containing about 40 per cent. SiO_2 and 45 per cent. CaCO_3 .

The ore beds occur about 120 ft. below the main coal seams, and may be seen over a large area west of Dundee. On the same horizon ore is found in the Utrecht district.

The main source of our iron ore supply is at Prestwick, about 10 miles NE. of Dundee and 58 miles by rail from Newcastle. This has been proved to be an extensive bed lying very slightly off the horizontal, with occasional slight undulations, through a long ridge of hills. The outcrops round this bed may be traced for several miles, and in 1925 it was decided to open up on the Prestwick farm, where the outcrop ore appeared to show the greatest expanse. Here it was easily uncovered and served as the original supply of ore for the blast-furnace (about 30,000 tons).

This outcrop ore consisted of a hydrated oxide of iron of the following average analysis :

Oxide Outcrop Ore (Prestwick).

Iron. %	SiO ₂ . %	Al ₂ O ₃ . %	CaO. %	MgO. %	Mn. %	P. %	S. %	Loss on Ignition. %
49·25	8·00	4·20	0·50	0·45	0·43	0·15	0·04	15·00

The Union Steel Corporation constructed a railway line about 7 miles in length to connect with Tayside Station, at a cost of over £25,000, and established a properly equipped mining camp, as there was every indication that the area would yield a permanent supply of ore.

In the meantime an adit was driven into the hill which contained the main body of ore, and arrangements were made for intensive development. Within 30 ft. of the surface the deposit was found to consist of a uniform body of ferrous carbonate, black in colour and very dense. The bed varies in thickness from 3 ft. to over 10 ft., but the line of development lies now in the direction of the thicker portion, which appears to be unlimited in extent. Above the carbonate ore there exists a seam of shale about 10 in. to 12 in. thick covered by another thin band of anthracite coal 6 in. thick. The roof is a very sound sandstone and requires no timbering.

The ore has been found to be very uniform in analysis in all directions, the following being average analyses at different points :

Analyses of Prestwick Carbonate Ore.

Date.	Iron. %	SiO ₂ . %	Al ₂ O ₃ . %	CaO. %	MgO. %	Mn. %	P. %	S. %	Loss on Ignition. %
April 1926—42·80	5·50	2·60	0·75	0·65	0·44	0·14	0·14	28·10	
Oct. 1926—40·28	5·15	2·40	0·70	0·20	0·45	0·13	0·18	33·35	
Nov. 1926—41·02	4·45	2·55	0·70	0·30	0·50	0·12	0·15	31·90	
Jan. 1927—40·08	5·60	3·00	0·80	0·30	0·49	0·13	0·15	31·65	
Oct. 1927—41·20	6·30	2·70	0·50	0·20	0·56	0·14	0·14	30·90	

As will be shown later in more detail under furnace operation, a very important feature of this large ore body is the fact that it contains about 5 per cent. of free carbon in a very fine state of division. This renders the ore self-calcining and also promotes coke economy in the furnace, where it is easily reduced, partly through the disintegrating effect of heat on the laminated lumps of ore.

This ore may be classed geologically as a siderite of sedimentary formation, and it is doubtful if another such body of similar purity

and uniformity has yet been exposed in any other part of the world. The outcrop ore is softer in character, being hydrated oxide of iron of a limonite character, obviously produced by prolonged atmospheric action on the originally exposed carbonate. It is very interesting to observe at the mine how the light brown oxide gradually merges through the intermediate stages into the primary stage of dense black carbonate underground.

The main driving adit extends now close on to 2000 ft. into the hill, and other adits are being developed with mechanical haulage to enable large tonnages to be handled. Coal-mining principles have been introduced, utilising the pillar-and-stall system. At the present time about 300,000 tons of pure ore have been blocked out in pillars, the average thickness of the bed being in the neighbourhood of 6 ft. Even supposing the whole ore body only averages 2 ft. 6 in. in thickness, it is computed that the properties over which the Union Steel Corporation hold the rights contain not less than 60,000,000 tons of ore. This figure has been endorsed by Mr. F. A. Steart, a well-known mining engineer and geologist in Natal. Assuming that only 10 million tons are available or capable of economical extraction, this quantity would be sufficient for an output of 150,000 tons of pig iron annually over a period of about 27 years.

Although Natal has not been thoroughly prospected for iron ore deposits, the following are of interest owing to their quality, and are an encouragement for further prospecting.

Rodell's Farm.—This ore is a surface deposit of hydrated oxide of iron situated about 8 miles from the Prestwick deposit and near the railway. The overburden varies from a few inches to 2 ft., and the ore varies from 18 in. to 36 in. in thickness. The total quantity in sight is estimated at about 200,000 tons. Approximately 22,000 tons have been smelted at Newcastle in admixture with Prestwick carbonate ore, with satisfactory results.

A typical analysis of Rodell ore is as follows :

	%
Iron	50·05
Silica	5·95
Alumina	4·00
Lime	Trace
Magnesia	"
Manganese	0·57
Phosphorus	0·081
Sulphur	0·025
Moisture	10·00

This small deposit was very useful in the early stages while development was proceeding at Prestwick, as the ore is loaded into trucks very cheaply.

Hazledene.—This property is situated about 10 miles east of Dundee and 7 miles from the railway. The ore is a massive hematite rich in iron and low in phosphorus. So far as is now known the extent is small, probably about 70,000 tons. It appears to be a surface deposit averaging 5 ft. in thickness, and can be worked open-cast, the overburden being only 1 or 2 ft. A few hundred tons of this ore have been delivered on rail by ox-wagon, and smelted at Newcastle. The average analysis of these deliveries was as follows :

Iron	%
Silica	63·45
Alumina	1·85
Lime	0·35
Magnesia	0·45
Manganese	0·35
Phosphorus	0·30
Sulphur	0·029
Loss on ignition	0·048
	4·00

Dick's Farm (near Utrecht, about 20 miles from Newcastle).—This is another small surface deposit of soft brownish-red ore which for some years has been worked in a desultory fashion for the manufacture of oxide paint. Samples of harder ore picked out analysed as follows :

Iron	%
Silica	55·10
Alumina	8·75
Lime	2·95
Magnesia	0·85
Phosphorus	0·44
Sulphur	0·122
Loss on ignition	0·020
	7·35

Palmyra.—This is a curious deposit of calcareous ore situated near the Dundee-Vryheid Railway line, 10 miles east of Prestwick. It is farther under the surface, and boreholes have proved a quantity of approximately 100,000 tons. The analysis is as follows :

Iron	%
Silica	28·20
Alumina	0·98
Lime	0·85
Magnesia	25·10
Manganese	6·45
Phosphorus	0·61
	0·13

If the quantity should prove greater, it will be worth while opening out and using it with the Prestwick ore in place of limestone or dolomite as a flux.

Cokes.

Whatever the quality of the ore may be, blast-furnacemen fully recognise that the successful operation of a blast-furnace depends, in a large degree, on the satisfactory quality of the fuel available for smelting. Up to the present time the Union Steel Corporation have not been in a position to manufacture their own coke, but have depended on the enterprise of certain colliery companies in Natal to meet their requirements. Speaking generally, these collieries have tackled the problem in a very thorough manner, and by establishing and maintaining a good quality of coke have assisted in a large way in the establishment of the pig iron industry in this province on a sound commercial basis. The price, however, is still too high (average, 21s. 6d. at the ovens), and it will be necessary to secure a material reduction in order to bring down the cost of pig iron to a level profitable for export in the world's markets. In the near future it is expected that the Corporation will have a greater control over coke manufacture, either by a closer working arrangement with the present producers, or by erecting a coke-oven plant at the most economical point for the selection of coking coals and saving in railages.

Northern Natal possesses the only extensive areas of coking coal in South Africa, so far as is known at present. The Transvaal has rich coal-bearing areas, but mostly of a non-coking character. A number of collieries in the Transvaal have demonstrated by experiment that a coking coal exists, but in these instances it has been found that the coking coal only consists of a certain thin portion of the seam. For extraction this would involve selective mining. Up to the present one cannot see a commercial proposition in coke manufacture there, particularly as the average ash in Transvaal coal is higher than that in Natal coal.

The two areas in Natal which have been exploited on a large scale for coking coal are round Dundee and Vryheid. In the former the Corporation is served by the Dundee Coal Company, who operate a battery of Coppée by-product ovens at Waschbank, about 50 miles from Newcastle.

Average Analysis of Waschbank Coke (By-Product).

				Ash Analysis.			

With a preponderance of Dundee coke of denser character the furnace undoubtedly slows up through the decreased rate of combustion. Improvements, however, are being effected at the ovens, at the Corporation's suggestion, by charging the low volatile coal without compression. This, of course, may retard the output of the present coke-ovens, but for blast-furnace requirements it is essential to avoid excessive density, although for cupola practice it is often a good feature.

The low sulphur content of the Vryheid coke enables the furnace to carry a desulphurising slag with a low ratio of lime to silica. This naturally results in a saving in the cost of flux per ton of pig. In our case it has been estimated that a reduction in the coke sulphur from 1 per cent. to 0·75 per cent. results in a saving of flux of 9d. per ton. That is, whereas a $\frac{\text{lime}}{\text{silica}}$ ratio of 1·5 in the slag must be carried in the former case, it is possible to produce a similar iron with a 1·4 ratio in the case of all-Vryheid coke.

Fluxes.

The furnace was started up and ran for about six months on limestone obtained from the Taungs deposit in Bechuanaland, the distance from Newcastle being close on 400 miles. The stone was of excellent quality but expensive, owing to the long railage. Subsequently experiments were made with a dolomite obtained from Natal Spruit, near Johannesburg, 180 miles distant, where a large deposit was exposed. Results were quite successful and a large contract was entered into, thus saving about 10s. per ton of flux.

The average analyses of these stones are as follows :

	Taungs Limestone. %	Natal Spruit Dolomite. %
Lime	54·30	28·60
Magnesia. . . .	0·35	18·75
Silica	1·45	1·75
Ferric oxide	0·25	...
Ferrous oxide . . . .	...	2·55
Alumina	0·15	0·25
Manganous oxide . . . .	...	2·60
Sulphur	Trace	0·003
Phosphorus	0·003	0·004
Loss on ignition	43·25	45·90

The presence of 2·60 per cent. of MnO in the dolomite is an interesting feature, and the manganese appears to counteract any decreased desulphurising effect of the MgO in the resultant slag. Without the addition of manganese ore, the manganese in our basic pig can be maintained at about 1·5 per cent., which is found to be a considerable benefit in the open-hearth.

Air.

As this is the raw material used in the largest quantity, it is perhaps worth while mentioning the two main features regarding it :

(1) The altitude of Newcastle being 4000 ft. above sea-level, it follows that allowance must be made in the design of any blowing unit to give the required volume at N.T.P. In our case it is necessary to increase the revolutions of our reciprocating blowing engines about 11·3 per cent. to give the same weight of oxygen per minute as would be obtained at sea-level.

(2) Although temperatures vary from 100° F. maximum down to 22° F. minimum, the air on the whole is fairly dry, the average moisture content being about 4·25 grains per cu. ft. in spite of very hot days in the summer, with frequent heavy thunderstorms.

DESCRIPTION OF PLANT.

The blast-furnace has the following dimensions :

Height	70 ft. 0 in.
Bosh diameter	14 ft. 5 in.
Hearth	10 ft. 0 in.
Bosh angle	78°
Throat diameter	10 ft. 0 in.
Bell	6 ft. 0 in.
No. of tuyeres	8 (5½ in. diam.)

The hearth is fitted with a steel-plated jacket with external water spray, while the bosh cone is cooled in a similar manner. The tuyere belt is fitted with three rows of copper cooling plates which have proved very efficient.

The capacity of the furnace is about 150 tons per day.

The filling arrangements consist of a long trestle gantry with concrete bunkers from which the different materials are drawn into the standard type of barrows for hand-charging. These

barrows are drawn up by a steam-driven, double-cage hoist, and dumped into an ordinary type of bell and hopper. With cheap native labour available it was not considered advisable at this first stage to equip the furnace with a mechanical charger for the comparatively small output.

The iron is all cast in sand, the pig bed being traversed by a Morris crane of 10 tons capacity, which carries the beds of iron to a Lamberton pig-breaking machine from which the broken iron discharges into wagons for despatch or stock. An extension of the pig bed gantry also deals with a considerable amount of stock iron in combs.

The blast is supplied by two vertical reciprocating steam-driven blowing engines, compounded and equipped with an efficient condensing plant. Each engine is capable of delivering about 22,000 cu. ft. of free air per minute up to 12 lb. pressure at 60 r.p.m. Walker light disc air valves were fitted on the blowing cylinders after scrapping the original valves, which were unsatisfactory. These engines were originally used on the Rand gold mines as compressors, and were converted for our purpose by substituting larger air cylinders. Each engine is fitted with two air cylinders 60 in. \times 60 in. Engine speeds vary from 50 to 60 r.p.m., according to requirements. It is proposed eventually to install a modern turbo-blower, but so far the existing engines meet all requirements.

There are four Cowper stoves (one erected since blowing in), 70 ft. \times 20 ft., with $7\frac{1}{2}$ -in. checkers, giving a heating surface of 42,000 sq. ft. per stove. The gas-burners are similar to the Bradshaw type with a central air-tube, while secondary air can be admitted through two side regulators. Blast temperatures exceeding 1400° F. can be obtained, while a cold blast by-pass is provided for equalising or regulating the blast temperature on the furnace.

The boiler plant consists of five gas-fired Babcock and Wilcox units, each of 250 H.P., and generating steam at 160 lb. pressure. Special gas-burners were designed by Mr. A. K. Reese, which give a very intimate mixture of gas and air, while efficient combustion is always maintained by allowing the flame to pass through a checker firebrick wall in front of the tubes. This keeps incandescent and has proved a useful feature.

Great care was taken before starting to ensure a satisfactory water service, which would, if necessary, cope with a possible increase in the plant. The River Incandu, providing a never-failing supply of good soft water, is situated 2000 ft. from the engine room, which is roughly 40 ft. above the mean level of the river. The pump house at the river contains three Sulzer centrifugal pumps, each capable of delivering 1500 gallons per minute through a 24-in. Hume reinforced concrete pipe into a sump at the engine room. The pump house can be hermetically sealed, with access only through the roof. This is necessary in case of heavy floods, when the river has been known to rise 18 ft. in a day. At the engine-room sump the water is distributed to the overhead furnace tank and to the various condensers by further centrifugal pumps. The return water then flows by gravity into the river again at a slightly higher point, so that a large reservoir with cooling towers is not necessary. For emergency use and for maintaining a constant level in the engine-house sump there is a pond on the property with a reserve content of 2 million gallons of water, which can feed the system at any time. About $3\frac{1}{2}$ million gallons of water are circulated through the works each day.

The electrical power for motors and lighting is generated by a vertical triple*expansion Bellis and Morcom 500 kw., 500 volts d.c. set. The lighting system is supplied through a balancer set at 250 volts. There is a spare generator as a stand-by. As there is a surplus amount of blast-furnace gas, it has been possible to drive the electrical machinery for an adjacent brickworks ; also, at an early date it is expected to be possible to light the town of Newcastle and supply power to private consumers.

The slag from the furnace is removed in Dewhurst self-tipping ladles of 10 tons capacity each. This material has been found to make excellent railway ballast, and is also used in road-making and for concrete. At a future date the manufacture of cement on a large scale from the granulated slag is contemplated.

The works is equipped with a large engineering workshop and an up-to-date laboratory, which have been important factors in the successful operation of the furnace.

A small foundry is attached to the plant for the manufacture of railway chairs, utilising native labour. Extensions are being

made, and it is expected to meet all requirements of the railways in the near future.

NOTES ON OPERATION OF BLAST-FURNACE PLANT.

Blowing-In.—After the completion of all plant details, the blowing-in was effected in June 1926, the charging being as follows :—First, 10,000 lb. of coke was placed in the hearth, followed by timber filling to a point 2 ft. above the tuyeres. Above this 36,000 lb. of coke blank was charged, followed by 54,000 lb. of coke blank with the limestone necessary for the two sets of coke. The ore round commenced at 600 lb., the coke round weighing 5400 lb. throughout, and, on filling the furnace, the ore had reached 5400 lb., or roughly one-half of the normal burden.

The following are the actual analyses of the materials used :

Coke : Waschbank By-Product.

	%
Silica	5.22
Alumina	4.17
Lime and magnesia	0.56
Ash	11.5

Ore : All Prestwick Outcrop.

	%
Iron	48.50
Silica	7.00
Alumina	3.65
Lime and magnesia	0.75

Limestone : Taungs.

	%
Silica	1.65
Alumina	0.18
Lime	53.95

As the stoves were cold, extra fuel was required to allow for any delay in heating up the stoves by gas, while naturally a little more margin was allowed in the primary stages of blowing-in than would be necessary at a corresponding plant in England, owing to lack of previous experience of South African materials and the comparatively raw staff who were to assist in the operations. It may be mentioned here that the management could only depend on one experienced furnaceman on each shift, namely, the foreman,

who was imported. The native Zulu labour had still to be tested, but eventually proved very adaptable and hard working.

The furnace was started in the American fashion, using 5-in. tuyeres and applying light blast, without any interval for natural draughting. A small cast of foundry iron was obtained from the tapping hole within 24 hours, and the normal process was then followed, with successive increments of burden. The early casts showed 4 to 5 per cent. of silicon, and the furnace was maintained on good foundry iron with 2.5 to 3 per cent. of silicon for 10 days or so until a definite routine was established, when a basic iron burden was put on.

No difficulty was experienced in the filling and charging operations; the natives were well coached and quickly grasped the fundamental ideas, and an orderly system was soon developed. For a temporary period extra white supervision was necessary in connection with the operation of the hoist and distribution on the bell, &c., but this was soon withdrawn and the native organisation came under the shift foreman direct.

More difficulty was experienced on the pig bed for the first week or two, as the natives, whose mentality in many respects resembles that of children, ran away at the first sight of molten slag and iron. Many changes had to be made, but they gradually became accustomed to the new conditions, and, by the exercise of patience and tact on the part of the management, became very efficient workers. As most of the Zulus can only work a maximum of six months in the year away from their farms, it became necessary to be continually training new native boys to take the place of those departing. This naturally threw more responsibility on the few leading white men in charge of different sections.

Within 14 days the furnace had attained an output of about 125 tons per day, and operating results proved quite satisfactory on the whole. Subsequently the output reached the scheduled capacity of the furnace, that is, 150 tons. In view of the restricted outlet for the product, however, it has not been considered advisable to maintain the maximum output of the furnace, so that the 5-in. tuyeres have remained. These will be replaced by 5½-in. tuyeres when occasion demands.

The first year's campaign has not run entirely smoothly, owing to many varying conditions, such as (1) variations in the quality

of the ore through the progressive phases of development at the mine ; (2) mechanical troubles with blowing engines, which were however, satisfactorily overcome ; (3) continuous training of labour, necessitating careful selection and rejection, with the main object of reducing labour costs to a minimum ; (4) climatic changes, including frequent tropical downpours of rain, with occasional cloudbursts in the summer-time.

The campaign lasted about 15 months, during which period 56,209 tons of iron were made, the output being restricted as mentioned above. The furnace was closed down on October 1, 1927, owing to the excess of stocks of pig iron, but it will resume operation after a period of 8 or 9 months. It is then anticipated that the full capacity of the furnace will be required for a more prolonged period, to meet the increasing demands for pig iron at the steelworks and foundries.

Smelting of Native Ores.—For the first few months it was necessary to use practically all the oxidised outcrop from Prestwick, as described under raw materials. This contained 48 to 49 per cent. of iron and was frequently very friable, producing an excessive amount of fines. The ore was very easily reduced, but the loss in flue-dust was at times rather high. Owing to the steep bosh of the furnace, however (78°), hanging troubles were not experienced, and we are convinced that for smooth and economical operation the steep bosh is the main requirement even in comparatively small furnaces.

As the mine was developed the pure carbonate ore was reached, and this was mixed in gradually increasing proportions with the oxide ore at the furnace. As the smelting of raw carbonate ore was a rather unusual procedure in standard practice, and in most circumstances quite uneconomical, it was at first concluded that the ore must be calcined in the best way that could be devised. With the carbonate ore containing 40 per cent. of iron, the actual content of CO_2 in the raw carbonate ore is roughly 31 per cent., while the free carbon content is 5 per cent. On complete calcination the free carbon is lost, as well as the CO_2 , but there is a gain of about 5 per cent. through final oxidation of the ferrous oxide to ferric oxide, thus reducing the net loss to about 31 per cent.

Assuming calcination to be 90 per cent. efficient, a product should be obtained containing almost 58 per cent. of iron, although

SiO_2 and other impurities would rise in proportion. From the point of view of saving carriage, and the possible objections to driving off the large quantity of CO_2 in the furnace, it would appear that calcining at the mine is the only sound policy, thereby obtaining a concentrated material free of CO_2 .

As a result of our experience, covering a long period of observation, our ideas on the subject have, however, been considerably revised. In the first place, the carbonate was calcined in open piles at the mines, using about 5 per cent. of small coal. It was soon discovered that the 5 per cent. of free carbon in the ore was more than ample to promote calcination without extraneous fuel. Several thousand tons were calcined in large heaps and put through the blast-furnace in admixture with the oxide ore. Although it was possible to reach an average of 56 per cent. in the calcine, the process was objectionable for the following reasons :

(1) Lack of uniformity of product. The greatest heat was generated in the centre of the heaps and caused excessive clinkering ; the material was then difficult to size, and consequently proved refractory in the furnace. The outside layers were never completely burnt, and thus a variable analysis existed throughout the heap, with consequent greater difficulties in burdening the furnace.

(2) Deterioration in mechanical condition of the ore was accentuated by further repeated handlings. The hard, dense carbonate ore on being heated was split up into laminations which became more friable, and the ultimate proportion of fines became appreciably increased. Under more precise control in closed kilns this difficulty might be overcome by allowing the lumps of ore to attain a stage in calcination where vitrification just commenced. But the problem is a difficult one, as actual clinkering must be avoided, and in open heaps, where the ore is in the slightest degree under-burnt, friability results.

(3) Expensive handling of the raw ore. A large amount of native labour was required for building the heaps, while refilling tubs and transporting calcine back to loading bunkers at the mine was no light task, though, of course, mechanical methods could be introduced eventually to save labour costs.

It was naturally concluded that certain advantages could be reaped by installing a system of closed kilns, but in the meantime small proportions of raw carbonate had been smelted in the furnace.

The results were so encouraging that before installing kilns it was decided to experiment, as far as possible, with the carbonate, and obtain data, keeping in view the fact that a credit must be shown that would at least balance the extra railage cost of raw ore.

Before the end of 1926 development of the mine was proceeding well, but there were many engineering and mining difficulties to get over before the maximum tonnage could be guaranteed for daily requirements, while the stock of outcrop ore was almost exhausted. For an output of, say, 4200 tons of pig iron per month it was necessary to ensure a continuous supply of 10,500 tons of carbonate per month. In order to tide over the development period, and also the period of experiment on carbonate ore, it was decided to take a quantity of oxide ore (50 per cent. iron) from Rodell's Farm (see above); this ore was taken purely as a temporary expedient, and for some months has constituted about 40 per cent. of the average mixture, working quite satisfactorily.

The proportion of carbonate in the mixture was steadily increased from December 1926, when $33\frac{1}{3}$ per cent. was functioning well, up to 50 per cent., and by June $66\frac{2}{3}$ per cent. carbonate was yielding excellent results. The furnace drove quite smoothly on the whole, although the presence of some slightly bituminous coal from the upper seam at times caused periods of high pressure through a little wedging action in the furnace. The loss in flue-dust was decreased, and the gas was still highly combustible at the stoves and boilers in spite of an increased content of CO_2 .

For a short period before closing down the furnace it was possible to make a run on all raw carbonate, and the results were very gratifying, particularly in respect to coke consumption. With all oxide ore the average coke consumption had been in the neighbourhood of 2100 lb. per ton of pig. This was steadily reduced until for a short period on basic iron with all raw carbonate the low figure of 1734 lb. was obtained.

We are quite convinced that as a general practice raw carbonate can now be smelted with a consumption not exceeding 1800 lb. over a prolonged period, making allowances for maximum driving and any minor disturbing factors that arise. We have not yet reached final conclusions on all aspects of the subject, as it is desirable to make certain observations over a larger period; but the main principle has been established that the fuel saving,

combined with the better mechanical condition of the ore as carbonate, and uniformity of operation, amply compensate for the adverse railage factor.

It has been evident that sufficient surplus heat was generated in the upper regions of the furnace to promote calcination without any loss of heat at the hearth, while the 5 per cent. of free carbon is a fuel addition which, on the basis of $2\frac{1}{2}$ tons of ore per ton of pig, is equivalent to—

$$\frac{5}{100} \times 5000 \times \frac{100}{86} \text{ lb.} = 292 \text{ lb. of coke per ton of pig.}$$

Principles of Carbonate Ore Smelting.—Elaborating this subject a little further we should like to co-ordinate our operating experience with the present recognised theories of blast-furnace reactions, and any discussion or criticism that may arise from the statement we make can only be helpful in connection with a subject of undoubted general interest.

Unlike calcination in the open air, the ore resulting from the action of heat in the furnace shaft is a ferrous oxide—not Fe_2O_3 . The process of iron smelting, speaking broadly, consists in the abstraction of oxygen from the oxides of iron and the melting of reduced iron sponge. It should follow, therefore, other things being equal, that the lower the state of oxidation of the ore, the less work the furnace has to perform, as the heat requirements for melting iron and slag in the hearth are constant. The lower oxides of iron of mineral formation, such as magnetite, occur in exceedingly dense masses, so that it is their mechanical condition which interferes with reduction, rendering them refractory. Although the extra oxygen from the higher oxide of iron involves an increased exothermic reaction with the carbon monoxide in the shaft, this means a greater quantity of CO which has to be generated previously at the tuyeres from coke—an expensive fuel.

If the work to be done in the shaft is reduced by having an ore in a lower state of oxidation, that work will be performed more efficiently. Less work, then, is thrown on the hearth, and a smaller coke requirement is sufficient for this.

Again, less coke in the hearth means less air to be blown, while, incidentally, there is less moisture to be decomposed, and the air can also be heated to a higher temperature owing to its reduced velocity through the stoves.

Further economy in coke consumption is then arrived at by the further saving through the somewhat smaller weight of slag which has to be melted in conjunction with the reduced proportion of coke ash. Also, the fact cannot be ignored that the minimum weight of coke to be burnt per ton of pig promotes faster driving of the furnace, with a cutting down of radiation, conduction, and cooling water losses per ton of pig. One might express the final coke saving mathematically as the sum to infinity of a series of terms in geometrical progression, each saving in coke automatically involving a further saving because of reduced slag, higher blast heat, &c., these economies decreasing by a fixed ratio.

Summing up this theoretical consideration, it appears quite uneconomical to oxidise the lower oxide of the carbonate ore in a calcining heap or a kiln simply to reduce it again in the furnace.

TABLE I.—*Coke Consumptions recorded during Campaign.*

Period.	Raw Carbonate in Mixture, %	Coke per Ton of Pig. Lb.
Half-year ending Dec. 31, 1926 .	25	2218
Half-year ending June 30, 1927 .	52	2091
3 months ending Sept. 30, 1927 .	59	1995
August, 1927	58	1941
Sept. 15 to 30, 1927	100	1734

The coke consumptions recorded during the campaign are given in Table I. Although the results are naturally affected to a certain extent by many other variable factors, one can observe the progressive decrease in coke consumption as the percentage of carbonate ore increases.

It is also interesting to record the average analyses of blast-furnace gas taken over a series of determinations during normal working conditions at the furnace (see Table II.). We commenced with all oxide ore from the Prestwick outcrop, and followed the investigation through, until, for a short period, we were able to observe the effects of working on 100 per cent. carbonate. The estimations were taken with a Standard Orsat apparatus.

TABLE II.—*Variation in Gas Analysis with Increase of Raw Carbonate.*

Raw Carbonate in Burden. %	Average Gas Analyses.			Ratio CO/CO ₂ .
	CO ₂ .	CO.	Total Carbon Oxides.	
Nil (all oxide) . . .	10·9	27·9	38·8	2·56
33 $\frac{1}{3}$	12·5	27·4	39·9	2·19
50	13·5	27·3	40·8	2·02
66 $\frac{2}{3}$	14·45	27·5	41·95	1·90
100	15·0	27·8	42·8	1·85

It will be observed that in each phase the percentage of CO in the gas is practically constant. The CO₂, however, rises steadily, and the percentages of the latter when plotted graphically against the percentage of carbonate in the ore mixture show almost a straight line up to 66 per cent. It is intended, however, to follow up the investigation by taking a longer series of gas analyses of the higher proportion of carbonate, as there is much scope for ascertaining valuable information on the relation between the CO/CO₂ ratio and particular furnace conditions in our special practice. Up to a certain point it would appear that the extra CO₂ in the gas corresponds roughly by weight to the CO₂ in the carbonate ore.

There is also a steady average drop in the gas temperature as the percentage of carbonate rises in the mixture, other things being equal, until for the higher proportion temperatures as low as 180° F. have actually been observed. As previously suggested, this is confirmation of a natural conclusion that, less oxygen being carried in with the ore to oxidise CO to CO₂ in the shaft (an exothermic reaction), less heat is evolved in the shaft, with consequent lower temperatures of the top gases.

Analyses of Pig and Slag.—Using a mixture of roughly equal parts of Dundee and Vryheid cokes, the slag analyses given in Table III. represent the best conditions of working for the corresponding grades of iron. For high-silicon irons it is usually advisable to use $\frac{1}{3}$ Taungs limestone in order to keep the manganese down to 1·25 per cent. About 80 per cent. of our output, however, is of basic quality for the steelworks.

TABLE III.—*Analyses of Pig Iron and Slag.*

Grade of Iron.	Pig.				Slag.				Ratio CaO + MgO SiO ₂ .
	Si. %	S. %	P. %	Mn. %	SiO ₂ . %	CaO. %	MgO. %	Al ₂ O ₃ . %	
Basic . . .	1.00	0.05	0.30	1.50	31.0	28.0	18.5	19.0	1.5
No. 1 Foundry	2.75	0.02	0.30	1.25	32.0	33.5	11.5	20.0	1.4

Furnace Records for August 1927.—These are given for one typical month, using a mixture of carbonate and oxide ores.

Output : 4152 tons { Basic pig . . . 74%
Foundry pig . . . 26%

Average Analyses of Products.

	Pig.	%		Slag.	%
Silicon	1.42	SiO ₂ . . .	.	31.23
Sulphur	0.051	CaO . . .	.	28.47
Phosphorus	0.31	MgO . . .	.	18.36
Manganese	1.42	Al ₂ O ₃ . . .	.	19.45
			S . . .	.	1.75
			MnO . . .	.	0.73
			FeO . . .	.	0.55

Raw Materials per Ton of Pig.

Carbonate ore . . .	2697 lb. = 58%	<i>Analysis of Ore Mixture (as recd.).</i>				
Oxide ore . . .	1931 „ = 42%	Fe.	SiO ₂ .	CaO.	MgO.	Al ₂ O ₃ .
		%	%	%	%	%
Total ores . . .	4628 „	43.7	8.0	0.30	0.20	3.8

Analysis of Coke Mixture.

Coke	1941 lb.	Carbon.	Ash.	Sulphur.	H ₂ O.
		%	%	%	%
		86.03	12.13	0.89	0.95

Analysis of Dolomite.

Dolomite	1617 lb.	SiO ₂ .	Al ₂ O ₃ + Fe ₂ O ₃ .	CaO.	MgO.
		%	%	%	%
		2.2	3.5	28.6	18.7

Slag per ton of pig, 1500 lb.

Average blast pressure	9 lb. at engines
„ blast temperature	1160° F.
„ gas temperature	310° F.
„ engine revolutions	51 per min.
„ air blown per min.	19,900 cu. ft.
„ moisture content of air.	3 grains per cu. ft.
Weight of ore per round (6 barrows)	11,344 lb.
„ coke per round (6 barrows)	4,758 „
„ dolomite per round (3 barrows)	3,963 „

Working Costs of Production.—The working costs of production recorded below relate to the month of August, 1927.

Output : 4152 tons.

Raw Materials.	Consumption per Ton of Pig. Lb.	Weight of Material Used. Tons.	Price per Ton, Delivered.	Total Cost.	Cost per Ton of Pig.
				£ s. d.	£ s. d.
Iron ores :					
Prestwick carbonate	...	5599			
Rodell oxide	...	4009			
		9608	10s. 5d.	5,004 6 10	
Manganese ore	...	59	31s. 2d.	92 5 8	
Total ores	4657	9667	...	5,096 12 6	1 4 6
Coke	1941	4030	28s. 3d.	5,692 13 7	1 7 5
Dolomite	1617	3356	13s. 0d.	2,181 16 0	0 10 6
Total raw materials				£12,971 2 1	3 2 5
Coal : Boilers, 153 tons			} 9s. 6d.	£120 13 0	0 0 7
Loco., 80 „					
Sundries, 21 „					
Salaries : No. of Staff, 15				547 10 0	
Wages : Operating : 25 Europeans				669 11 4	
175 Natives				444 5 6	
Maintenance : 22 Europeans				382 1 2	
29 Natives				86 8 11	
Total salaries and wages				£2,129 16 11	0 10 3
Compound Expenses (accommodation and feeding all native labour)				£199 5 0	0 1 0
Stores : Operating				215 18 7	
Maintenance				320 15 7	
				£536 14 2	0 2 6
Laboratory				92 17 7	0 0 5
Sundry and General Charges				307 0 0	0 1 6
Total Working Cost (excluding depreciation and interest charges)				£16,357 8 9	£3 18 8

Tuyeres and Coolers.—During the campaign of 15½ months only one tuyere was lost, and no coolers ; the furnace ran for 14 months without losing a single tuyere. The steep bosh, combined with a good water circulation, was no doubt largely responsible for this regularity. The feed pipes (1¼ in. diam.) for both tuyeres and

coolers entered at the bottom with the outlet at the top, and this system prevented any possibility of the accumulation of sediment.

Stoves and Boilers.—These maintained their efficiency for the whole period without cleaning, thanks to the efficient dust catchers. The fine dust which accumulated in the checkers was removed about every three days by firing a “gun” underneath the checkers. The boilers were taken off in turn for cleaning throughout about once every three months. The dust problem is, however, not a serious one, and with carbonate ore becomes negligible. There is thus no need, in our opinion, for any special system of gas cleaning.

GENERAL AND ECONOMIC CONSIDERATIONS GOVERNING THE PIG IRON INDUSTRY IN SOUTH AFRICA.

This subject opens up an important field for discussion, and is perhaps a little beyond the scope of a practical paper on blast-furnace practice. One of the authors, however, has been considerably involved in the technical controversy that is still taking place between the Union Steel Corporation and the Union Government. The latter are proposing to pass a Bill whereby a State-controlled iron and steel industry shall come into being, with its centre at Pretoria in the Transvaal, their fundamental reasons being as follows :

- (1) Large deposits of iron ore exist round Pretoria.
- (2) It is a convenient distributing centre for the largest industrial centre of the country, which is the Rand.
- (3) State control of a vital key industry would bring about the immediate acquisition of the necessary capital to expand the industry to meet the further requirements of South Africa for finished steel products, it being assumed that private enterprise is not sufficiently progressive.
- (4) It would afford partial relief of the unemployment question as regards white labour. This factor appears to be a particularly important one with the Labour party, who at present control the balance of power in the Government.

The average industrialist and business man in South Africa does not favour State control of any new industry, but is prepared to support a State-aided iron and steel industry, which already

exists in the Union Steel Corporation, in respect of bounties granted on each ton of pig iron produced. Private enterprise is more conducive to economical working, and in a young country it is better to build up the industry in gradual stages on the foundation of practical experience.

The number of white men to be employed in the contemplated new works is comparatively small, as for cheap production of raw iron and steel one must be prepared to employ the lower-waged native labour to the utmost. Cheap native labour for unskilled operations is one of the chief assets in the development of South African industry. It is in the future subsidiary industries that cheap iron or steel will create employment for more Europeans.

Reverting to the technical aspect of pig iron manufacture, the whole case for private enterprise must lie primarily with the experts' consideration of the available reserves and quality of iron ores. The authors are not qualified to express a final opinion as to the most economical centre for a large blast-furnace plant. From actual experience, however, it has been proved that any decision in favour of Pretoria should be reserved pending a further investigation by experts of the resources of Natal, and particularly the Prestwick ore deposits.

The Pretoria ore reserves are undoubtedly very large, but the ore is of a quartzite character containing 47 per cent. of iron and 21 per cent. of silica. In the Government scheme, it is proposed to mix this with about 40 per cent. of a rich hematite ore from the Crocodile River, about 130 miles north of Pretoria. This latter ore also exists in very large quantities, but it is 60 miles from rail-head, which would involve new railway construction. The coke consumption required for smelting this mixture of ores is undoubtedly much larger than is the case with Prestwick ore, as confirmed by the Government technical report.

Again, it has been clearly demonstrated that the Transvaal is deficient in supplies of coking coal. It would thus be necessary to carry a large proportion of the latter from Natal (Dundee or Vryheid) to Pretoria, a distance of about 300 miles, for the manufacture of coke at the site. This involves very heavy railway charges.

The Prestwick ore deposits in Natal are now developed on such a scale that it is possible to state with every confidence that future

reserves of a uniform grade of ore will not be less than 10 million tons. In all probability the tonnage will greatly exceed this.

Newcastle was chosen as the site of the first blast-furnace, largely on account of the abundance of water in the neighbouring river, and the possibility of developing the local coal seams for coking, while the enterprising municipality offered special inducements to encourage the industry.

In view of the heavy carriage on the raw carbonate ore and the determination of its smelting properties with low fuel consumption, the natural outcome at the moment seems to be the establishment of the permanent blast-furnace plant at the Prestwick ore mine. The chief coking coal areas are in close proximity, while at Newcastle further investigation is required to determine the amount of coking coal available. There is also a river within a few miles of the ore mine, which will provide the water supply.

The question whether the raw or semi-finished steel shall be manufactured adjacent to the blast-furnace plant in Natal is another issue which cannot at the moment be discussed. Both Prestwick and Newcastle, however, are in a more favourable position for the export of any surplus pig iron through Durban.

The future of the industry in South Africa is assured, as abundant natural resources exist, and with the growth of the population and development of other industries there is great scope in the variety of products that can eventually be manufactured. At present the Corporation's steelworks at Vereeniging are producing sections of all kinds, light rails, bars, wire and reinforcing rods, while the steel casting department caters for the numerous requirements of the gold mines, railways, &c. At an early date a steel tube works will be in operation, to be followed by sheet and rail mills. As regards foundry iron, Newcastle now supplies practically the whole of the foundries in South Africa, and the quality has emerged from the severest tests against imported iron with a first-class reputation. The cost of production will be lowered very considerably later, as coke will eventually be manufactured very cheaply from Natal coals, the present contract price being artificially high. With increased ore tonnages, the cost of mining operations will also be reduced.

As regards the selection of the final site for the industry, other things being equal, it will be largely a question of the cost of

assembling the raw materials required per ton of pig, plus the cost of distribution of products to the main consuming centres. The incidence of carriage on industrial raw materials in South Africa is a very serious one, and with the high rates at present existing costs of production are controlled very largely by this factor.

In conclusion, the authors wish to tender their thanks to the Chairman and Directors of the Union Steel Corporation for their co-operation in allowing them to make use of the various official records and data. The Chairman, Major Butler, through his encouraging direction, has invariably made their duties most interesting.

A COMPARISON OF THE MOST IMPORTANT METHODS EMPLOYED IN THE CLEANING OF BLAST-FURNACE GAS.¹

By V. HARBORD (LONDON).

INTRODUCTION.

THE efficient cleaning of blast-furnace gas is one of the many problems which have confronted the manufacturers of iron and steel for many years, as only by this means can full benefits be obtained from this source of fuel. The large amount of gas evolved from the blast-furnace plant has been one of the main difficulties met with in the design of cleaning plants, but there are at the present day several very satisfactory cleaners working, whereby enormous direct savings are being made in the actual use of coal throughout the works, and indirect savings in repairs to hot blast stoves, boiler cleaning, and general efficiency in the plant.

Although results obtained from individual plants have been published, so far as the author is aware no independent detailed works results over a reasonable period of a number of plants are available, from which a comparison of the relative efficiencies of different types of plants can be made. It was thought that actual operating figures would be of interest, and with the consent of the directors and the co-operation and assistance of the staffs of a number of works in this country, the actual works records have been placed at the disposal of the author, the information given as to the general results thus obtained being embodied in this paper.

Gas-cleaning plants may be conveniently classified in two main classes—dry cleaners and wet cleaners—and the former can be further subdivided into those which filter the gas and those which remove the dust from the gas by electrical precipitation.

¹ Received March 2, 1928.

The best-known dry cleaners of the filtration type are the Halberg-Beth and the Kling Weidlein wire mattress cleaner, whilst the Lodge-Cottrell is the only type of electrostatic cleaner which has established itself in this country.

The wet-cleaning plants at work in this country are frequently of composite design, but they all depend essentially on getting an intimate mixture between a fine spray or mist of water and the gas, either by means of spraying or scrubbing in towers or by fan disintegrators of the Theisen type, or by a combination of both.

Another distinction which is frequently made between types of gas cleaners is between those which are capable of treating the gas hot and thus preserving the sensible heat, and those which necessitate cooling the gas prior to cleaning; of the former the electrostatic and the Kling Weidlein are the most important examples, and considerable importance is attached by the patentees or manufacturers to this saving in sensible heat. This advantage is not so great as may appear at first sight, as the gases at the higher temperature are capable of carrying a larger amount of water vapour, which will retard combustion. By cooling the gases below their dew point, water will to a certain extent be removed, and the loss of sensible heat will be partly balanced by obtaining a drier gas for combustion, notwithstanding the intimate contact with the water during cleaning.

There are great difficulties in comparing the results obtained by the various types of cleaners, as few types are designed to clean down to the same extent, nor are the conditions under which each is operating similar in all cases. The quantity, quality, and fineness of the dust all have a considerable bearing on the question, as it is obviously an easier matter to remove the coarser particles than the extremely fine material, and the variation in the dust from the same furnace from hour to hour makes it extremely difficult to generalise. Again, it is manifestly unfair to compare the relative cleaning efficiency of a Kling Weidlein apparatus with that of the Halberg-Beth, as the former is only claimed to act as a primary cleaner.

With certain types of cleaners—more especially those of the wet type—a certain amount of latitude is possible in this respect by regulating the amount of water used, and it is a matter for

the management to decide at which point the benefits obtained from additional cleaning become no longer economical.

When comparing the results obtained from different types of cleaners, the dust content of the final gas is the most suitable basis of comparison, bearing in mind, of course, whether the apparatus is designed as a primary or a final cleaner. Somewhat misleading figures are sometimes given under the name of "efficiency," as expressed in the percentage of the dust extracted; almost any type of dust-catcher will extract coarse dust, and the efficiency so defined will depend almost entirely on the relative coarseness and the quantity of the dust in the crude gas. With a dirty gas a good "efficiency" can thus be shown, although the resulting cleaned gas may still contain a large amount of dust. The desired object is to obtain a gas which does not contain more than a certain amount of dust after cleaning, and this should be the basis of comparison.

The dust contents in the gas reported in this paper were not determined in all cases by the same apparatus at the different works; different methods were adopted as the result of individual experience. With skilled operators the differences in the methods employed in sampling should not appreciably affect the results obtained.

In the choice of a suitable cleaning plant, there are a number of points in addition to the actual final dust content of the gas which require careful consideration, such as power consumption, water supply, disposal of dust, and whether the dust is of any value for briquetting or for the recovery of potassium salts.

With wet cleaners, when the quantity of water is limited or the flue-dust is required for briquetting purposes, the installation of the Dorr thickener in conjunction with the cleaning plant enables the greater portion of the water to be recirculated, and the dust can be collected in the form of a thick sludge and run out into storage bays and dealt with as desired.

It was hoped at first to get definite information as to the indirect savings obtained by the various methods of cleaning, but this has proved too difficult to compute with any degree of accuracy, as there are so many factors which affect the results. In some cases, coincident with the installation of cleaning plant, hot blast stoves have been redesigned, different filling bricks put

in, and new and more efficient types of burners have been introduced, all of which improvements have led to saving. On the other hand, full benefit is not being obtained in some cases, owing to the gas not being fully utilised pending alterations to other parts of the works. It is therefore practically impossible to estimate the indirect saving in refractories and repairs, due to the introduction of gas cleaning, which has, however, even under unfavourable conditions, more than justified itself by saving in cost of repairs and maintenance. In some cases a smaller number of stoves are being used and a higher blast temperature maintained, giving a greater blast-furnace efficiency.

A short description of each type of cleaner is given below, together with any special works conditions considered likely to affect materially the results obtained.

WET CLEANING PLANTS.

Plant I.—Scrubber and Fan Washer.

This plant is designed for cleaning for gas engines, and is cleaning 600,000 cu. ft. of gas per hour from 4 to 5 grm. down to 0·02 grm. per cu. m. The dirty gas enters the water spray cooling towers at a temperature of 190° C., is cooled down to 37° C., and leaves with a dust content of 0·8 to 1 grm. per cu. m. It then passes to a Jenkin fan in which water is injected in a fine spray, and, leaving this with a dust content of from 0·2 to 0·3 grm. per cu. m., it is finally cleaned to 0·02 grm. in a Theisen washer. The power consumed in this plant is 160 kw., which is equivalent to 0·275 unit per 1000 cu. ft. of gas cleaned; the water used for the same quantity of gas is about 30 gallons. The cost for labour, power, stores, and repairs for this plant, according to works records for a three months' period, was 0·195d. per 1000 cu. ft.

Plant II.—Scrubber and Disintegrator.

This plant is cleaning gas only for stoves and boilers, soaking pits, &c., and although the plant was designed for dealing with only 800,000 cu. ft. per hour, it is actually cleaning 1¼ million cu. ft.

The crude gas, containing 4 to 5 grm. per cu. m., is cooled in a Zschocke tower from about 80° to 140° C. to 36° C. It is then passed either into a Zschocke fan which reduces the dust content to 0.25 grm. per cu. m., or to a new Theisen disintegrator by which the dust content, if determined at a distance along the main at which all the spray has settled, is found to have been reduced to approximately 0.02 grm. per cu. m. The power and water consumed on this plant per 1000 cu. ft. of gas cleaned are respectively 0.08 unit and 11½ gallons when using the Zschocke fan, but with the Theisen disintegrator 0.13 unit and 13½ gallons are required. The total cost for labour, maintenance, and power on this plant over a prolonged period was given as 0.0896d. per 1000 cu. ft. of gas cleaned. During this period both the Zschocke fan and the Theisen disintegrator were working at different times.

Plant III.—Wet Cleaner with Scrubbers, and Disintegrators.

This plant is designed to wet-clean the gas from four blast-furnaces, and is treating rather more than 5,000,000 cu. ft. per hour. The gas, containing from 2 to 3 grm. per cu. m., is collected in a common main 9 ft. 3 in. in internal diameter, and enters three scrubbers at a temperature varying from 100° to 200° C. These scrubbers are 72 ft. high and 15 ft. in diameter, and are packed with 134 tiers of wooden grids with 1½-in. spacings. Water is impinged on to a cast-iron plate from eighteen 2-in. nozzles to form a fine spray. The gas passes from the scrubber to three Theisen washers, each capable of dealing with 2,118,000 cu. ft. of gas per hour at N.T.P., and is finally dried in three cyclone driers 7 ft. in diameter and 16 ft. high, from which it is taken to the clean gas main and distributed to stoves and boilers. The clean gas leaves at a temperature of about 40° C. and contains from 0.03 to 0.04 grm. of dust per cu. m. About 40 per cent. of this gas is finally washed for gas engines in an old Theisen plant, but the power and water figures given apply only to the gas cleaning down to the condition required for stoves and boilers. The sludge from the cleaning plant is taken to a Dorr clarifier which enables nearly 90 per cent. of the water to be recirculated. The clarifier, further details of which are given later, is 86 ft. in diameter and deals with 5000 gallons per minute, and the clarified

water passes to settling ponds, where it is cooled by one hundred and twenty $\frac{5}{8}$ -in. sprays and recirculated. The thickened sludge is disposed of as a waste product.

The power used by the circulating pumps and Dorr thickener is 0.038 kw.-hr. per 1000 cu. ft. of gas cleaned, and for the three Theisen washers 0.18 kw.-hr., giving a total of 0.218 kw.-hr. per 1000 cu. ft.; the water circulated and the make-up water are respectively 5.4 gallons and 0.6 gallon per 1000 cu. ft.

The plant has only recently been put into operation, so that maintenance and repairs are practically negligible. The labour required is 2 men per shift, which entails a charge of 0.006d. per 1000 cu. ft. of gas cleaned. The water is obtained from the river, so that the direct cost of cleaning the gas to the required condition for stoves and boilers works out, on the basis of power at $\frac{1}{2}$ d. a unit, as 0.115d. per 1000 cu. ft. of cleaned gas.

Plant IV.—Brassert Tower and Theisen Disintegrator.

This plant, which has only recently been started up, and will probably be considerably extended, has a capacity at present of 2,500,000 cu. ft. per hour, and is cleaning rather more than 2,000,000 cu. ft. per hour to the extent required for stoves, boilers, soaking pits, and reheating furnaces.

The plant consists of a single Brassert tower with sprays and hurdles to break up the water and gas. The tower is about 70 ft. high and 14 ft. in diameter, and the water circulated is about 50 gallons per 1000 cu. ft. of gas. The gas, containing about 6 grm. of dust per cu. m., enters the tower at a temperature between 180° and 240° C., and leaves at about 20° to 25° C. It then passes to one of two intermediate driers in which the excess of moisture is removed by a sudden reversal of the gas flow and by the gas impinging on fresh surfaces. The gas is then taken to one of two Theisen disintegrators, the second being in reserve as it is found necessary to thoroughly clean them out about once in six months. The water circulated in the Theisen machine is about 5 gallons per 1000 cu. ft. of gas cleaned. The gas is then passed into one of two Bischoff driers by which the mechanically held moisture is removed by baffles and frequent reversals of the direction of flow of the gas. The final gas contains from 0.15

to 0.20 grm. of dust per cu. m. under the present working conditions.

An interesting series of tests was carried out at this plant on the effect of varying the quantity of circulating water in the tower and in the disintegrator; they showed that in both parts of the cleaner the quantity of water could be very considerably reduced without any reduction in the cleaning of the gas, but in practice it has been found that if the minimum amount of water be used, which is about 25 gallons on the tower and 3 gallons on the Theisen machine per 1000 cu. ft., the Theisen disintegrator rapidly furs up. This plant is so situated that the charge for the water supply represents only the cost of the power for circulation, and this amounts to a difference of only about 0.01 unit per 1000 cu. ft. for the additional water. The actual power used was given as 0.15 unit per 1000 cu. ft. The labour to run the plant is two men per shift and supervision which amounts to 0.024d. per 1000 cu. ft.

As regards repairs and maintenance, the plant is practically new and has only been running a few months, so that no figures are available, but it would appear that these should be very low, as the whole system consists merely of circulating pumps. The six-monthly clean and overhaul of the Theisen is carried out by the operators on the plant with the help of fitters, &c., and is estimated to cost about £4 to £5 each time.

The capital cost of this plant was about £17,400.

Plant V.—Brassert Scrubbers and Sprays without Disintegrators.

This plant is similar in some respects to Plant IV., in that it is a Brassert washer, but it differs in that Theisen disintegrators are not installed in conjunction with the towers. The plant consists of two Brassert washers 15 ft. in diameter, No. 1 being 86 ft. high and fitted with a bottom cone, and No. 2, of later design, being 65 ft. high and having no such cone, and has a capacity of about 5 million cu. ft. per hour.

At present No. 1 washer only is in use, owing to the blast-furnace plant not being in full operation, and $2\frac{3}{4}$ million cu. ft. of gas are being cleaned per hour. The tower is packed with wooden hurdles on to which jets of water are sprayed, the gas in

its upward journey being intimately mixed with the down-flowing spray of water. The gas before leaving the tower is subjected to a high velocity water spray, and after being made to turn a number of double bends it enters the drier or mud catcher tangentially. This is a cylindrical chamber, the bottom of which tapers into the down-comer main for the gas. The centrifugal force due to the tangential entry throws the coarser moisture particles to the sides of the cylinder, and this is assisted by a high-pressure spray of water in a very fine state of division impinging on the stream of gas from above which serves as a carrier of the moisture particles to the sides of the tube. This moisture-containing fine dust is trapped in an expanded part of the down-comer, and is drawn off, the cleaned and partially dried gas passing along the main, where it is further dried by a sharp change of direction at the bottom of the down-comer. It then enters the clean gas main feeding the stoves, boilers, &c. This main is fitted with drain cocks every 50 ft., which are opened every 24 hours. Fig. 1 is a sketch showing the construction of the Brassert tower and spray drier.

The water and sludge are taken in an open culvert to the Dorr thickener, which is 86 ft. in diameter. The clarified water passes to a hot well, and is then pumped up into a cooling tower and recirculated. The sludge is run out into bays and allowed to dry; it is proposed to put down a sintering plant to treat this material for the blast-furnace plant.

The gas, containing 5 to 6 gm. of dust per cu. m., first enters a primary dust catcher of the cyclone type and then enters the Brassert tower. It enters the clean gas main with a dust content of about 0.4 to 0.5 gm. per cu. m.

The total water required for the operation amounts to 29 to 37 gallons, and the power required is 0.029 unit per 1000 cu. ft. of gas cleaned. The make-up water due to wastage and loss with sludge amounts to approximately 5 per cent., say, $1\frac{1}{2}$ to 2 gallons per 1000 cu. ft. of gas. In an appendix is given a table showing the temperature of the gas and water at various points on the system and gas analyses over a period of several weeks.

The labour in this plant is not considered, as the pumps have all been installed in the existing pump-house and have entailed no extra men for operation. The washery itself is visited by

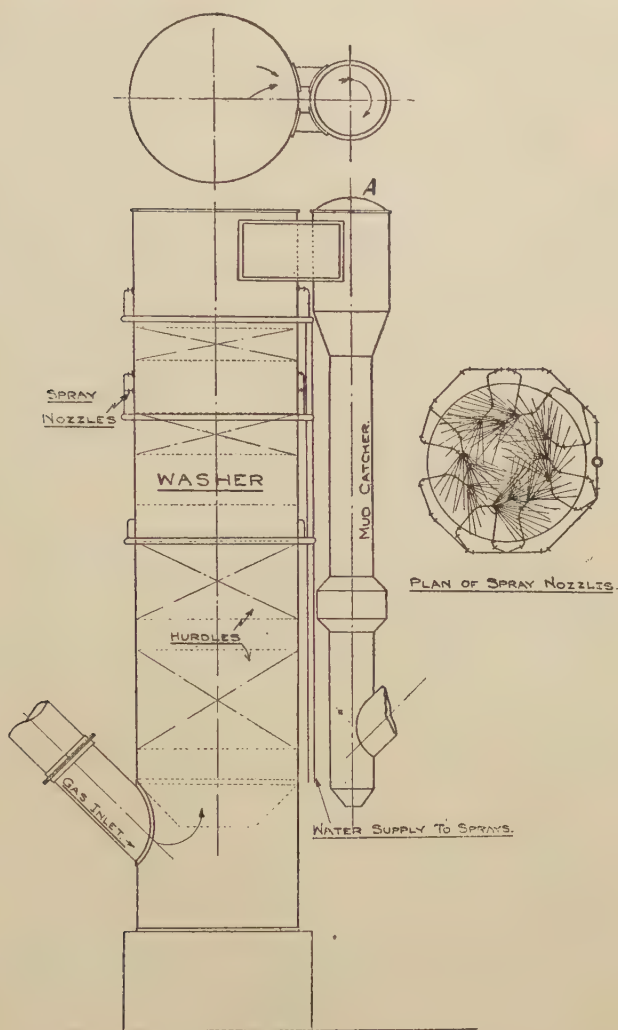


FIG. 1.—Brassert Washing Tower and Mud Catcher. The gas on leaving the spraying tower, in which the coarser dust is removed, enters the mud catcher tangentially, whereby some of the moisture, carrying dust with it, is deposited on the sides of the tube. The atomising water spray at *A* impinging on the gas from above at high pressure carries the finer moisture particles to the tube surface. The wet slurry is trapped in the expanded part of the tube and withdrawn.

the stove tenders at regular times, but no extra men have been employed since the plant was put into operation. Actually a proportion of these men's time should be allocated to the gas-cleaning plant, but it was not possible to obtain any figure for this. As regards repairs, the plant has only been running a few months and no figure can as yet be given.

A short description of the Dorr clarifier as installed to deal with blast-furnace slurry may be of interest. The apparatus installed at Plant V. consists of a circular tank 86 ft. in diameter into which the slurry is brought. There are four arms fitted to a vertical rotating shaft, two long and two rather shorter, which make one revolution in 20 minutes, drawing the settled sludge to the centre, whence it is discharged by special sludge pumps. The power expended is very low and is included in the figure given above. A typical test of the clarifying effect of this apparatus is as follows :

	Grains per cu. ft.
Inlet water :	32·45 suspended solids, 98·42 in solution.
Outlet water :	3·39 suspended solids, 93·91 in solution.

The amount of dried sludge obtained from the Dorr thickener is about 3 tons per day, of which the following is a typical analysis :

	%	
FeO	23·04	} total iron = 44·20%
Fe ₂ O ₃	37·43	
SiO ₂	10·48	
CaO	4·60	
MgO	Trace	
SO ₃	1·45	
P ₂ O ₅	0·133	
MnO	1·67	
Al ₂ O ₃	11·40	
Loss on ignition	8·40	

The capital cost of the Brassert towers, Dorr thickener, &c., was given as £12,500, the total cost including new mains and other alterations being about £30,000.

DRY CLEANERS.

Plant VI.—Lodge-Cottrell, Pipe Treater Type.

This plant was designed to clean 2,000,000 cu. ft. of gas per hour, but as the output of the blast-furnaces has been increased

since its installation, it is estimated that it is dealing with about 3,000,000 cu. ft. of gas per hour. It is of the "pipe treater" type, and consists of six compartments, each containing 64 pipes, through which a nichrome wire is suspended from an insulator above. The dust is deposited on the inner walls of the tubes by the electrical discharge. Each battery of tubes is fitted with its own separate electrical unit, and is mechanically rapped every hour to shake the dust down, the current being temporarily cut off. It is probable that a considerable amount of the dust which is found in the clean gas test is brought over immediately after opening up the compartments after rapping, as it is not possible in practice to give the dust sufficient time to settle completely in the hopper after rapping.

The plant has been in operation for some years, and considerable difficulties were met with in the early stages in the choice of suitable wires for the discharge electrodes; this difficulty has now been overcome by the use of nichrome wires. The author was also informed that considerable improvements have been made in the rectifiers and insulators, which now give very little trouble. The gas enters the cleaner containing on an average 5 to 6 grm. of dust per cu. m. and at a temperature of from 180° to 230° C.; it is cleaned down to a dust content of from 0.4 to 0.6 grm. per cu. m. and leaves the apparatus at a temperature of from 120° to 180° C. It was stated that the inlet temperature could rise to 425° C. without causing trouble. Details of tests taken over a period of one month are given in an appendix.

The dust content is considered to be higher than would be the case if the plant were working to its designed capacity, but, on the other hand, the cost of cleaning per 1000 cu. ft. would be materially increased. The considerable difficulty encountered at first in handling the dry dust from the apparatus has been overcome by discharging it into a culvert and flushing it away by water; by this means the labour is reduced.

One chamber is laid off every month for a complete clean out and overhaul. The power used in the plant amounts to about 0.013 unit per 1000 cu. ft., and the labour required is three men per shift and a foreman on day shift. The cost of labour amounts to 0.0181d. per 1000 cu. ft. of gas cleaned.

Stores and repairs over a period were given as costing 0·0023d. per 1000 cu. ft., and the overall cost of cleaning—power, labour, and repairs, stores, renewals—amounted to 0·026d.

The capital cost of a similar plant at to-day's prices would be approximately £30,000.

Plant VII.—Lodge-Cottrell, Plate Treater Type.

This plant is composed of eight chambers, through which the gas is passed in parallel. The insulated wires are suspended between vertical plates which take the place of the tubes in the pipe treater type; the dust is deposited on the plates by the electric discharge from the insulated wires, which are charged with unidirectional current at high tension. Each chamber is fitted with two sets of plates, the gas being thus cleaned in two stages. About 2,000,000 cu. ft. of gas per hour containing about 5 gm. per cu. m. are passed, and the cleaned gas, carrying on an average 0·4 gm. per cu. m., is used under stoves and boilers. Trouble was encountered in the early days with the breakage of the insulators, but improvements have increased the average life of an insulator to about 12 months. The dust in this plant is removed by hand-labour, and is rather difficult to handle owing to much of it being very fine in character; a considerable proportion of the wages cost is spent in dealing with this material, which at the present time has no market value.

The amount of dust recovered per week amounts to about 35 tons, which is equivalent to approximately 3·75 gm. per cu. m. of dust cleaned, and forms a fairly accurate check on the percentage extraction of the plant.

The cost of power consumed on the plant over a period was given as 0·03d., wages 0·014d., insulators 0·001d., repairs and stores 0·0015d., making the total actual working costs for this plant 0·0465d. per 1000 cu. ft. of gas cleaned.

The capital cost of the plant was given as £20,000.

Plant VIII.—Lodge-Cottrell, Plate Treater Type.

This plant is designed to treat 6,000,000 cu. ft. of gas per hour. It consists of twelve chambers working in parallel;

each chamber is fitted with four banks of electrodes, the two banks on the crude side being worked in each case from electrical units separate from those on the clean main side; so that one side of the treater acts as a crude dust cleaner and the other side as a final dust cleaner. The installation consists of six electrical units, but only four have been put into service, as the plant has not yet operated at full capacity owing to the blast-furnace department not working at its maximum output. Two of the electrical machines operate the crude gas side of the plant, the others the semi-clean gas side. The dirty gas usually contains from 4 to 6 grm. of dust per cu. m. and enters the plant at about 200° C. A drop in pressure of 0.5 to 0.6 in. water-gauge and in temperature of about 100° C. occurs during its passage through the apparatus, and a final dust content of about 0.3 grm. per cu. m. is usually found in the clean gas.

At these works the blast-furnace practice varies considerably from time to time, according to the varying proportion of calcined and raw ore used, and this has a very considerable bearing on the dust content of both the dirty and clean gas. In an appendix is given a series of actual tests carried out on different ore burdens illustrating this effect.

The labour required to operate the plant is one man per shift, and one man cleaning out on day shift only. The dust is withdrawn in the dry state from the hoppers into wagons and is somewhat difficult to handle; it has no market value. The power required to work the plant (that is, 4 machines) is 0.0225 unit; wages, including dust disposal, cost 0.0063d., and stores 0.0017d. per 1000 cu. ft.

The plant has only been put into operation comparatively recently, and, as is frequently the case, there has been a certain amount of trouble in the early stages; consequently, maintenance, replacements, and engineers' time on the plant have been considerably in excess of what will be normally expected, and these figures are therefore not included. It is believed that these troubles were only such as are usually met with in starting up a new plant, and that before long they will be to a great extent overcome.

The capital cost of this plant was given as £55,000.

Plant IX.—Halberg-Beth Filtration Plant.

This plant is treating approximately 2,000,000 cu. ft. of gas per hour, containing about 3 to 4 grm. of dust per cu. m. The gas first enters the towers, in which it is air-cooled to a temperature of 75° to 100° C. (water being added if necessary) in order to prevent the burning of the bags and to deposit moisture; it is then reheated to 80° to 120° C., so that it will pass through the bag house without the temperature dropping below the dew point. The temperature control is most important in these plants.

The bag house consists of 2 units, each of 20 compartments having 12 bags, that is, a total of 480 bags. Each of these 12-bag compartments in each unit is automatically shaken hourly to remove the dust, and during this time the current of gas is reversed in order to blow the dust from the pores of the bags. The gas on leaving the bag house contains on an average 0·025 grm. of dust per cu. m., and is used in this condition for stoves, boilers, &c. A portion of the gas which is required for gas engines is further cleaned in a water-spraying tower and dried in a tower packed with wooden grids. The dust content of the gas for the engines is about 0·004 grm. per cu. m. Particulars of weekly chart readings over long periods showing temperatures, power consumption, bag renewals, and dust content are given in an appendix. It will be seen that the bag renewals amount to 10 to 15 per week, and that the power consumed averages 0·075 to 0·085 unit per 1000 cu. ft. of gas cleaned.

On a three-months period when the plant was operating normally, the following figures per 1000 cu. ft. of gas cleaned were obtained :

Total wages	0·0287d.
Bags	0·0072d.
Stores and repair materials	0·0046d.

The all-in cost of running the plant, omitting depreciation and establishment charges, was 0·0778d. per 1000 cu. ft. of gas.

The capital cost of this plant at to-day's prices is approximately £23,000.

Plant X.—Halberg-Beth Plant.

This plant, designed to clean $4\frac{3}{4}$ million cu. ft. of gas per hour, is composed of four separate units, each consisting of ten double compartments containing 12 bags in each part, that is, 240 bags per unit, making a total of 960 bags. It is equipped with five Green economisers for controlling the gas temperature, to prevent either the burning of the bags or the deposition of moisture during filtration. Only one blast-furnace was operating at these works at the time that the gas-cleaning tests were made, so that only two units were in service. The hourly treatment of gas was estimated to be 1,800,000 cu. ft.

The whole of the gas cleaned is only required for burning under stoves and boilers, consequently there was no necessity to install the final spray washer and drier, as in the case of the last plant described. The comparison of the cleaning results must therefore be made on the dust content when the gas leaves the bag house. It was stated that one object of this plant when installed was the recovery of potash from flue-dust, but at present this is not being carried out. The dust content of the gas on entering the plant, as obtained over a series of tests for four or five weeks, details of which are given in an appendix, appears very variable, but is generally of the order of 5 grm. per cu. m., and the cleaned gas on leaving contains from 0.1 to 0.2 grm. per cu. m., although some tests show a much higher figure. These results do not compare very favourably with the previous plant figures, but it must be borne in mind that this gas is only required for burning purposes. In the previous case some of the gas is used in gas engines, and the bag filtration must reduce the dust content as far as possible to enable the final sprayer to lower it sufficiently for that purpose. In this plant the life of the bags is considerably longer than in the previous one; under the conditions at this works it is more economical to get a longer life from the bags even at the expense of a somewhat less efficient cleaning of the gas. The power expended in this plant amounts to 0.11 unit per 1000 cu. ft. of gas cleaned, labour costs to 0.032d., and repairs, renewals, &c., including bags, to 0.0034d. The total cost of cleaning per 1000 cu. ft. is 0.0603d.

Plant XI.—Kling Weidlein Cleaner.

This type of cleaner, which depends upon the gas being passed by its own pressure through chambers in which are fixed wire-wool mattresses, has been introduced into some works in this country from America, but generally they have not been a success. Their object is only to give a gas suitable for burning in stoves and boilers ; they are very cheap to operate as regards both power and labour, and undoubtedly serve to remove a considerable portion of the dust without losing the sensible heat of the gas.

This plant, which consists of five chambers, was one of the earliest erected outside of America, and was designed to clean $3\frac{1}{2}$ million cu. ft. per hour. It is generally considered that the plant was rather too small to deal with that quantity of gas, and in the later designs more chambers have been added for plants of this capacity. The gas contained about 6 grm. of dust per cu. m. on entering the plant, and though numerous experiments were carried out, varying both the thickness of the mats and the coarseness of the wire-wool, it was not found possible to reduce the dust content regularly below 2 to 3 grm. per cu. m. Considerable mechanical difficulties were also met with, such as the breaking of the yokes during the periodical automatic shaking to clean the mattresses. By the time the mattress has become sufficiently clogged with dust to form a satisfactory filter, trouble is liable to arise on account of back pressure.

A series of tests carried out in 1923 is given in an appendix. The plant has not been in operation since the middle of 1925.

Plant XII.—Kling Weidlein Cleaner.

This plant, consisting of a ten-compartment plant, is dealing with 3,200,000 cu. ft. per hour, each chamber being automatically cut off and shaken every two minutes. It appears to be the most successful one in this country, and although the dust content in the clean gas is not as low as is desired, the upkeep and the cost of the cleaning are very low. The conditions of temperature under which this type of cleaner operates are most important. If the temperature of the gas becomes

too high there is considerable destruction of the wire mattresses, and if, on the other hand, it drops low enough to deposit moisture, the wet dust sets in the mattresses, and the chambers are put out of action. The gas temperature is therefore kept at about 150° to 200° C. In this particular plant, the cleaner is so situated as to meet these conditions best, and consequently more satisfactory results have been obtained than at other works.

The average dust content of the crude gas is 7 gm. per cu. m., and it is cleaned down to an average of 1.8 gm. Details of a series of dust determinations from this plant are given in an appendix. The power requirements are 0.003 unit, labour 0.004d., repairs 0.001d., wool and stores 0.0005d. per 1000 cu. ft. of gas cleaned; the total direct cost of cleaning is 0.019d. for this amount of gas.

The capital cost of this plant was given as about £20,000 at to-day's prices.

Two other plants of this type were visited, but it was found impossible to obtain results, as they had not been maintained in good working condition. In neither case could satisfactory results be obtained, even by using varying grades and thicknesses of the wire-wool, and at the present time the gas is being passed through to remove such dust as the mattresses are capable of retaining; no records are being kept, nor would it be fair to carry out tests on the apparatus as at present working.

From the results obtained from the four plants of this type, this cleaner hardly appears suitable for working under the conditions in this country.

Possible Developments.

There are two other types of apparatus which may be of interest, although no full-scale tests have yet been carried out on blast-furnace gas. The first is a new type of primary cleaner known as the Grant-Jones cleaner. It is in some respects similar to the Kling Weidlein apparatus, in that it is essentially a primary cleaner for supplying stoves and boilers, that the gas is filtered hot through a special material, and that the sensible heat of the gas is retained. In this apparatus the filtering medium is ground

flint, which is evenly distributed over a travelling belt in two layers, coarse and fine; the belt of woven wire completely separates the upper half of the chamber, into which the crude gas is brought, from the lower half, so that all dust is drawn through the filtering bed. The flint with the dust is discharged by the endless travelling belt after its passage through the machine, and is then sieved free of the dust, regraded and automatically returned into the system. A small experimental plant was tried in the Midlands, and a larger plant is now being tried out at works in Leicestershire. A preliminary run has been made, but it is considered too early to do more than draw attention to what may develop into a valuable method of primary cleaning. The capital cost should be moderate, and there appears no reason to anticipate high operating costs.

The second type of cleaner has only been tried out on a blast-furnace plant in one small-scale experimental plant, where the conditions did not sufficiently resemble those required for satisfactory working for any reliable data to be obtained. It is of the cyclone type, which, as is well known, has been tried in very many different forms without any great success. This one has, however, been evolved after many years of experiment, and differs essentially from the ordinary types; it has given very satisfactory results in the removal of zinc dust in zinc smelting works, where a great number have been working efficiently for many years. The great attraction for a cleaner of this type is the extremely low capital cost of the plant, as it is believed by the inventor that satisfactory cleaning with this plant can be done with an outlay of hundreds of pounds instead of the thousands spent on the usual types of cleaners.

COMPARISON OF THE RESULTS OBTAINED.

In Table I. are tabulated the results obtained from the plants described above, from which it is possible to obtain a general comparison of the different types of plants from different aspects.

In the following comparisons the results obtained at Plant I. must not be included, as this plant is treating only a small volume of gas for engine purposes. Plant IX. (Halberg-Beth) may,

TABLE I.—Comparison of Blast-Furnace Gas Cleaners.

1. Plant No.	2. Type of Plant.	3. Approx. Capital Cost at to-day's Prices. £ per million cu. ft. capacity.	4. Capacity of Plant. Cu. ft. per hr.	5. Gas Cleaned per Hour at N.T.P. Cu. ft.	6. Average Dust in Orude (Gas. Gm. per cu. m.)	7. Average Dust Content in Clean Gas. (Gm. per cu. m.)	8. Electric Power. Units per 1000 cu. ft. Gas.	9. Water. Gals. per 1000 cu. ft. Gas.	10. Labour. Pence per 1000 cu. ft. Gas.	11. Repairs, Stores, and Renewals. Pence per 1000 cu. ft. Gas.	12. Direct Labour. Pence per Hr. per Hr.	13. Operating Costs. Pence per 1000 cu. ft. Gas. ¹	14. Remarks.
I.	Spray tower, Jenkin fan, and Theisen washer	Not available	600,000	600,000	4 to 5	0.02	0.275	30	0.0406	0.0105	...	...	...
II.	Zschocke tower, Zschocke fan, or Theisen disintegrator	Do.	800,000	1,250,000	4 to 5	0.25 with Zschocke 0.02 with disinte- grator 0.03 to 0.04	0.08 0.13	11½ 13½	0.0245	0.0040	30.62	0.0685 Zschocke fan 0.0935 Theisen	...
III.	Scrubbers and Theisen dis- integrators	Do.	Over 5,000,000	Over 5,000,000	2 to 3	0.15 to 0.20	0.218	5.4 circu- lated 0.6 make-up	0.006	Negligible at present	30.0	0.115	New plant. Dorr thickener and water recir- culated New plant
IV.	Brassert tower and Theisen disintegrator	7,000	2,500,000	Just over 2,000,000	6	0.15 to 0.20	0.15	55	0.024	Negligible at present	48.0	0.099	New plant. Dorr thickener and water recir- culated. Only working half plant
V.	Brassert tower, and sprayers	2,500	5,000,000	2,750,000	5 to 6	0.40 to 0.50	0.029	29 to 37 1½-2 make- up water	Nil. None extra em- ployed	Negligible at present	Nil	0.013	New plant. Dorr thickener and water recir- culated. Only working half plant
VI.	Lodge-Cottrill (pipe type)	15,000	2,000,000	3,000,000	5 to 6	0.40 to 0.60	0.013	...	0.0181	0.0023	54.3	0.0269	...
VII.	Lodge-Cottrill (plate type)	10,000	2,000,000	2,000,000	5	0.40	0.025	...	0.014	0.0025	28.0	0.0290	...
VIII.	Lodge-Cottrill (plate type)	9,000	6,000,000	3,250,000	4 to 6	0.30	0.0225	...	0.0063	Not avail- able under present conditions	22.47	0.0180 ²	4 electrical machines working out of 6
IX.	Halberg-Beth	11,500	2,000,000	2,000,000	3 to 4	0.025 0.004 after final spray for engines	0.08	Very little; only por- tion of gas washed Nil	0.0287	0.0118, including bags	56.4	0.0805	...
X.	Halberg-Beth	Not available	4,750,000	1,800,000	5	0.1 to 0.2	0.11	...	0.032	0.0034, including bags	59.6	0.0904	Only half plant working
XI.	Kling Weidlein	Do.	3,500,000	3,500,000	6	2 to 3	...	...	...	0.0015	...	...	...
XII.	Kling Weidlein	6,000	3,500,000	3,200,000	7	2	0.003	...	0.004	0.0015	...	...	...

¹ Based on power at ½d. per unit.² Labour, power, and stores only; no maintenance or renewals.

however, be fairly compared, as only a portion of the gas is being finally washed for engine purposes, and the additional cost of this washing is comparatively small.

In the author's opinion the results obtained by the Kling Weidlein plants show that this type of machine does not give even a reasonably clean gas for stoves and boilers, and that to obtain satisfactory results it must be worked in conjunction with a subsidiary cleaning plant. In the present comparisons of working costs, therefore, this type of cleaner is disregarded.

(a) *Comparative Cleaning Powers.*—From the above tests it appears that the best results can be obtained by Halberg-Beth plants and by washing plants composed of spray tower and Theisen disintegrators, and that wet cleaners with spray towers only and the electrostatic cleaners are capable of cleaning down the gas to about 0.4 to 0.5 grm. per cu. m. The advantages obtained by burning gas cleaned to 0.4 or 0.5 grm. are very great compared with uncleaned gas, but there is a considerable difference of opinion whether this is sufficient to give the best results for water-tube boilers and similar purposes.

The exact point to which cleaning the gas for stove and boiler purposes can be economically carried (that is, to obtain the maximum heat development and minimum cost in refractories and repairs in relation to the cost of cleaning) is still an open question, but general considerations seem to indicate that a gas containing not more than 0.2 grm. per cu. m. gives sufficiently good results, and it is doubtful if further expenditure to decrease the dust below this is worth the extra cost.

(b) *Power Consumption.*—In this respect the best results are obtained by the electrostatic plants, of which the "pipe treater" gives the lower figure. The latter plant is, however, working 50 per cent. over capacity and yielding a rather less clean gas. If working to the capacity for which it is designed and assuming the same power were used, the figure would be 0.02 unit per 1000 cu. ft. of gas. The Brassert tower and spray cleaner is next in order, the Halberg-Beth plants and Zschocke fan plant come next, and the most costly in respect to power are the combined tower and Theisen disintegrator plants.

(c) *Labour Costs.*—These are somewhat difficult to compare with any degree of accuracy, as they depend very considerably

on the quantity of gas passing, as, provided no additional plant is put into operation for increased gas cleaning, the same labour can operate the plant for larger quantities of gas. For this reason the cost of labour in pence per hour, irrespective of the quantity of gas cleaned, is given in column 12 in Table I. ; for comparison purposes it seems that these figures and those in column 10 should be considered together. They show that the labour costs on the Halberg-Beth plant are highest, but that in the other cases there is probably very little difference in this respect. Plant V. must be regarded as exceptional, as the plant has been so arranged that all the labour involved is carried out by men employed on other work. Actually a portion of these men's wages should be allocated to the gas-cleaning plant, but no figures could be obtained on this basis.

(d) *Repairs, Stores, and Renewals.*—This item will depend to a very considerable extent upon the length of time the plant has been in operation, and the figures obtained under this heading are not strictly comparable. Plants III., IV., and V. have all been recently started up, and the wear and tear is consequently very slight. The most costly plant in this respect appears to be the Halberg-Beth, especially when being operated to reduce the dust to a minimum as in Plant IX. The difference between Plants IX. and X. is to a great extent due to the longer life of the bags in the latter, owing to the higher dust content permissible in the cleaned gas. There is not sufficient evidence regarding other plants to indicate any definite superiority in this respect.

(e) *Working Costs.*—In order to obtain some comparison of the working cost of these plants, an arbitrary figure for power at $\frac{1}{2}$ d. per unit has been taken, and the total cost for power, labour, repairs, and renewals computed on this basis. In the majority of cases power is probably being obtained at a lower figure than $\frac{1}{2}$ d., but this has been chosen as a reasonable basis for comparison. The figures for the nine plants under discussion are given in column 13 of Table I.

In this comparison no charge has been made for the water used in washing, as in most cases this is obtained for the cost of pumping (included in power figure), and in others where water is not so available Dorr thickeners have been installed, which reduce the water make-up requirements to a very low figure.

From the above figures it appears that, on the whole, the electrostatic plant comes out most favourably. The Brassert tower and spray plant shows actually the lowest figure, but as already stated, no labour is allocated to the plant, and no maintenance has yet been necessary. These figures certainly would be very low under ordinary conditions, and such a plant would no doubt compare favourably with the electrostatic apparatus. The Halberg-Beth costs are clearly very much dependent on the state of cleanliness aimed at, as reflected by the bag renewals, but if worked to full efficiency the cost of operating seems to be about the same as those of the combined tower and disintegrator plants.

(f) *Capital Cost of Plants.*—It has been extremely difficult to obtain figures for capital cost of plants, as in some cases where the plants have been of composite design different parts have been added at different times ; in other cases plants have been installed when prices were inflated during the post-war period, and actual figures under those conditions would be only misleading. In column 3 of Table I. are given the capital cost figures per million cu. ft. capacity for those plants for which it has been possible to calculate them at approximately present-day prices. Although the "capacity" of plants is a somewhat elastic figure, especially in the case of wet cleaning plants, this appears to be the most satisfactory basis to adopt for comparison. From these figures it appears that the plants for which the information has been obtained come in the following order, the most expensive being the electrostatic (pipe treater), followed by the Halberg-Beth, the electrostatic (plate treater), and washing towers and disintegrators, the least expensive being washing towers with sprays, even when the cost of the Dorr clarifier is included.

SUMMARY AND CONCLUSIONS.

As the result of the figures given above the following conclusions can be drawn :

1. If a dust content in the gas of about 0.5 gm. is considered sufficient for the purposes required, this can be achieved by a washer of the tower and spray type without disintegrators or by electrostatic plants. If a lower dust content is required, a

washer of the disintegrator type or a Halberg-Beth filtration plant is necessary.

2. The Kling Weidlein plant cannot be regarded as a satisfactory cleaner, and to obtain reasonable results it should only be used as a primary cleaner in conjunction with some other form of cleaner. Its capital cost is too high for a first-stage gas cleaner, and unless used in conjunction with an electrostatic cleaner one of its main claims (namely, retention of sensible heat) is lost.

3. The cost of operating the electrostatic plants appears less than most other types of plants, but the average dust content in the cleaned gas is higher than with disintegrator washers. The sensible heat is retained, but the handling of the dry dust has some disadvantages. Improvements are still being made with this type of apparatus which must be regarded as being still more or less in its infancy, and it will probably have a very big field in the future. The capital cost is high.

4. The most efficient type of wet washers are of the combined tower and disintegrator type. The cost of running such plants is, however, higher than other types of cleaner except the Halberg-Beth.

5. The Halberg-Beth cleaner, if due attention is given to renewal of bags, gives a lower dust content in the final gas, and its cost of operation is no more than that of the more efficient wet cleaners. The two main objections to this plant are its high capital cost and the handling of the dry dust.

The author wishes to thank the directors of those firms who have given permission for the results to be obtained from their works, and also the members of the staffs who have taken so much trouble in supplying him with the figures and in discussing details of the plants during his visits to their works.

APPENDIX.

PLANT V.—*Results obtained using No. 1 Brassert Tower for October and November, 1927.*

Date. Oct. 1927.	Dust Content of Clean Gas. Grm. per cu. m.		Date. Nov. 1927.	Dust Content of Clean Gas. Grm. per cu. m.	
	First Sample.	Second Sample.		First Sample.	Second Sample.
1	0.500	...	1	0.332	0.300
3	0.561	0.648	3	0.449	0.520
4	0.676	0.618	4	0.268	0.485
5	0.348	0.451	5	0.343	...
6	0.538	0.449	7	0.389	0.332
7	0.547	0.559	8	0.343	0.353
8	0.650	...	9	0.353	0.360
10	0.343	0.511	10	0.385	0.405
11	0.449	0.596	12	0.362	...
12	0.357	0.279	14	0.362	0.394
13	0.424	0.353	15	0.311	0.350
14	0.378	0.362	16	0.428	0.348
15	0.529	...	18	0.366	0.362
17	0.602	0.678	19	0.364	...
18	0.600	0.520	21	0.307	...
19	0.650	0.706	22	0.332	0.300
20	0.599	0.522	23	0.366	0.284
21	0.556	0.398	24	0.350	0.334
22	0.472	...	25	0.311	...
24	0.511	0.538	26	0.380	...
25	0.371	0.247	28	0.252	...
26	0.518	0.344	30	0.318	...
27	0.481	0.650			
28	0.247	...			
29	0.199	...			
31	0.499	0.366			

Average temperature of inlet water to towers, 20° to 25° C.

Average temperature of clean gas leaving plant, 20° to 25° C.

Average temperature of overflow water from Dorr thickener, 35° to 40° C.

PLANT VI.—*Dust Content and Temperatures of Blast-Furnace Gas during May, 1927, taken from the Lodge-Cottrell Gas-Cleaning Plant (Pipe Treater).*

Date of Analysis. May, 1927.	Dust Content.		Gas Temperatures.	
	Before Cleaning. Grm. per cu. m.	After Cleaning. Grm. per cu. m.	Before Cleaning. ° C.	After Cleaning. ° C.
2	3.30	0.34	215	138
3	6.20	0.60	184	127
4	4.32	0.52	240	166
5	4.60	0.44	217	142
9	6.40	0.50	178	124
10	6.20	0.58	180	118
16	5.64	0.52	213	149
17	5.42	0.66	247	166
18	4.74	0.60	192	133
19	6.62	0.58	240	160
23	6.42	0.56	260	184
24	4.82	0.52	247	188
25	5.60	0.52	238	160
26	4.26	0.46	195	150
30	5.40	0.46	220	154
31	7.30	0.56	244	160

PLANT VIII.—*Lodge-Cottrell Plant (Plate Type).*

Date.	Gas Temperatures.		Dust in Gas.		Percentage of Calcined Ore used in Blast-Furnace.
	Dirty Gas. ° C.	Clean Gas. ° C.	Dirty Gas. Grm. per cu. m.	Clean Gas. Grm. per cu. m.	
1927.					
Oct. 5	237	150	8.55	0.56	58.3
„ 11	183	112	4.65	0.25	
„ 12	232	141	4.90	0.50	
„ 13	204	136	3.70	0.31	
„ 14	217	114	4.35	0.49	
Average .	214.6	130.6	5.23	0.42	58.3
Nov. 16	181	95	4.00	0.19	41.7
„ 17	175	111	2.05	0.17	
„ 18	163	89	11.00	0.13	
„ 21	170	85	3.76	0.24	
„ 22	137	80	3.53	0.07	
„ 23	196	110	3.13	0.39	
„ 24	200	106	2.94	0.34	
„ 28	181	103	2.90	0.10	
„ 30	176	89	5.28	0.09	41.7
Dec. 8	153	89	2.47	0.05	
Average .	173.2	95.7	4.10	0.17	41.7
1928.					
Jan. 4	218	98	10.9	0.49	75.0
„ 5	254	119	6.61	0.96	
„ 10	208	86	2.42	0.39	
Average .	226.7	101.0	6.64	0.61	75.0

During the whole of the period only four of the electrical machines were in operation.

PLANT IX.—*Halberg-Beth Gas Cleaning Plant, 1926 and 1927.*

Date, Week Ending.	Total Volume of Gas Cleaned (N.T.P.).	Filter Bags Changed.	Total Dust taken out in Filtration.	Dust taken out (N.T.P.). Grm. per cu. m.	Dust Content of Clean Gas ¹ (N.T.P.). Grm. per cu. m.	Kw. per Million cu. ft. Gas Cleaned (N.T.P.).
1926.	1000 cu. ft.		Tons. Cwt.			
Jan. 9	306,181	15	30 12	3.60	0.002	80.4
" 16	301,102	11	41 19	5.28	0.003	81.0
" 23	307,378	5	38 10	4.73	0.003	71.1
" 30	319,254	4	47 3	5.30	0.004	81.3
Feb. 6	318,207	6	36 10	4.00	0.0045	84.8
" 13	320,906	10	35 13	3.83	0.004	83.8
" 20	320,726	20	37 16	4.10	0.003	85.5
" 27	328,201	23	33 0	3.23	0.004	85.1
Mar. 6	355,972	26	33 9	3.37	0.0025	76.9
" 13	365,782	16	31 7	3.07	0.003	72.7
" 20	391,809	16	32 12	3.00	0.004	73.0
" 27	388,878	6	32 12	3.01	0.002	71.3
Apr. 3	367,186	8	42 10	4.15	0.003	72.2
" 10	378,911	4	41 12	3.94	0.003	73.1
" 17	392,849	11	33 13	3.08	0.005	74.8
" 24	394,800	10	34 9	3.12	0.004	72.0
May 1	376,000	6	35 3	3.40	0.004	78.0
1927.						
Jan. 8	95,814	2	4 10	1.68	No analysis	78.0
" 15	247,707	7	16 18	2.70	"	74.0
" 22	256,747	8	31 9	4.41	"	85.0
" 29	353,163	14	31 9	3.11	"	74.0
Feb. 5	348,420	13	32 18	3.18	0.007	75.0
" 12	277,480	10	22 1	2.60	0.006	83.0
" 19	277,060	11	14 0	1.70	0.006	80.0
" 26	301,264	14	18 3	2.10	0.005	86.0
Mar. 5	260,980	17	18 0	2.40	0.006	87.0
" 12	270,900	23	24 10	3.14	0.006	75.0
" 19	295,800	34	25 0	2.94	0.005	71.0
" 26	301,550	37	27 4	3.24	0.007	77.0
Apr. 2	304,390	19	27 10	3.35	0.003	83.0
" 9	289,368	22	20 4	2.51	0.003	84.0
" 16	280,810	19	21 10	2.75	0.003	78.0
" 23	276,080	9	17 0	2.20	0.003	72.0
" 30	297,220	13	22 4	2.87	0.004	88.0
May 7	292,000	9	24 10	3.10	0.004	85.0
" 14	283,960	9	26 4	3.31	0.003	92.0
" 21	263,800	9	24 0	3.26	0.003	82.0
" 28	280,462	5	27 7	3.50	0.003	83.0
June 4	285,580	6	30 0	3.77	0.002	83.0
" 11	273,433	11	28 1	3.68	0.002	81.0
" 18	284,807	7	28 18	3.65	0.003	93.0
" 25	305,976	7	30 0	3.48	0.003	75.0

¹ After gas has passed through water-cooler and drier for use in gas engines.

Remarks.—Inlet temp., 70° to 90° C. Delivery temp., 70° to 95° C. Pre-heater temp., 80° to 120° C. Counterblast pressure from 4-in. water-gauge. Gas inlet pressure from 2-in. water-gauge. Gas delivery pressure from 5-in. water-gauge. Dust content of gas after passing through bag house only, 0.025 grm. per cu. m. Life of filter bags varies from 12 to 492 days; average, 285 days.

PLANT X.—*Halberg-Beth.*

Date.	Dirty Gas.			Clean Gas.			Average Daily Temperatures.		
	Rate of Sampling, Cu. ft. per hr.	Volume of Gas Sampled (N.T.P.), Cu. ft.	Dust Content of Dirty Gas (N.T.P.), Grm. per cu. m.	Rate of Sampling, Cu. ft. per hr.	Volume of Gas Sampled (N.T.P.), Cu. ft.	Dust Content of Clean Gas (N.T.P.), Grm. per cu. m.	Crude Main, ° C.	Cooled Main, ° C.	Pre-heater Bottom, ° C.
1927.									
July 28	5.2	12.1	0.353	230	94	93
" 29	3.5	59.5	0.141	238	96	96
Aug. 3	3.3	17.7	0.220	268	97	95
" 4	3.0	10.98	1.676	2.1	7.27	0.096	247	88	94
" 5	2.6	10.07	8.510	...	...	...	247	93	95
" 5	2.2	9.93	5.190	...	...	...	247	93	95
" 6	2.6	11.88	8.730	...	...	...	238	93	94
" 8	1.4	5.00	1.046	...	...	...	248	93	93
" 12	3.9	84.3	0.024	224	87	96
" 15	3.9	85.5	0.021	258	101	97
" 16	3.2	17.4	0.347	273	99	97
" 16	2.9	49.8	0.078	273	99	97
" 17	2.8	12.0	0.368	260	91	92
" 17	3.0	5.78	0.114	260	91	92
" 18	3.9	17.05	0.178	259	92	93
" 19	3.2	12.30	0.443	277	95	96
" 22	3.0	9.32	0.156	274	92	95
" 23	2.8	12.30	0.058	267	96	95
" 24	3.2	13.50	0.131	266	91	94
" 25	3.3	12.95	0.082	258	91	95
" 26	3.2	11.36	0.128	242	89	92
" 29	2.2	11.92	0.192	284	97	99
" 30	3.6	16.58	0.217	287	92	96
" 31	2.7	12.39	0.072	294	95	99
Sept. 1	3.5	16.48	0.117	279	91	94
" 2	3.8	23.00	0.133	289	98	99
" 3	3.2	10.98	0.145	286	95	97
" 5	3.9	18.07	0.162	278	94	96
" 6	5.3	26.65	0.128	280	98	93

Volumes corrected for an average temperature of gas as sampled of 20° C. No record kept of temperature of gas leaving plant.

The higher dust content in clean gas as compared with Plant IX. is due to gas being required only for stoves and boilers. Bag renewals are considerably less in this case.

PLANT XI.—*Kling Weidlein. 5-Compartment Plant.*

Date.	Dust Content of Dirty Gas. Grm. per cu. m.	Dust Content in Cleaned Gas. Grm. per cu. m.
Jan. 6	5.48	2.79
„ 12	5.50	2.59
„ 19	6.34	4.05
„ 25	6.21	3.32
„ 26	8.20	2.98
„ 27	6.76	3.18
„ 29	9.88	6.00
„ 30	7.31	3.60
Feb. 4	4.79	1.58
Average of 9 tests over 1 month	6.85	3.34

PLANT XII.—*Kling Weidlein. 10-Compartment Plant.*

Test No.	Temperature of Gas entering Cleaner. ° C.	Gas Pressure. In. Water-Gauge.		Dust Content. Grm. per cu. m.	
		Entering Cleaner.	Leaving Cleaner.	Dirty Gas.	Clean Gas.
1	110	3.75	2.0	9.67	1.87
2	143	3.0	2.25	5.15	1.43
3	143	3.0	2.0	8.83	1.87
4	197	2.5	1.5	9.56	2.78
5	160	2.25	1.5	3.39	0.77
6	149	2.25	1.5	5.26	1.25
7	193	3.0	2.0	11.90	2.23
8	190	3.0	2.0	5.22	1.56
9	177	3.0	2.0	5.40	1.44
10	190	6.0	5.0	6.76	2.00
11	188	3.5	2.5	6.93	1.53
			Average	7.10	1.86

DISCUSSION.

Mr. W. SIMONS (Member of Council) congratulated the author on his paper. The subject was very interesting and very important for the iron and steel industry, and the author had clearly set forth the advantages of the three or four different systems which might be employed. Personally, he thought there were only three which were of really practical assistance—the electrical deposition method, the wet washing, and the Halberg-Beth. The Kling Weidlein could hardly be regarded to-day as a successful gas-cleaning plant; he was responsible for the first plant put down in this country, but it was rather a disappointment to him, and he did not think it had any value as a primary cleaner. With regard to the others, there was no doubt in his mind that those who had put down particular plants were a little biased in favour of the type they had adopted. Although one might adopt a partial wet-washing system, or the electrical system, both of which were only suitable for rough cleaning, the proper course to pursue was to clean the gas perfectly. Rough cleaning might be of a certain value, but to get the full advantages of gas cleaning it was necessary to adopt either wet washing with disintegrating washers or the Halberg-Beth method. In considering which of those types to use, one must be influenced very much by the size of the blast-furnace plant. For a blast-furnace plant with five or six furnaces, there was a good deal to be said in favour of the Halberg-Beth, which produced perfectly clean gas, and had proved satisfactory and was largely adopted on the Continent. In his own case he had adopted simply the wet washing which was referred to in the paper, for rough-cleaning. That was only partially satisfactory, but even that was better than no gas cleaning at all. He had only one blast-furnace, and so could not consider the Halberg-Beth method, but he had been able to reduce the coal consumption by 400 to 500 tons a week. He would like to go further and adopt disintegrators in order to get more efficient cleaning.

Personally, he was not concerned so much with the relative merits of different plants as with the unfortunate fact that there were in this country large numbers of blast-furnaces still unprovided with any gas-cleaning plant at all. It was an elementary fact that it must pay the industry well to adopt gas cleaning, and he urged the blast-furnace people to do so. Those who did not adopt such an obvious advantage could hardly appeal with any justice for help as a depressed industry.

Mr. G. B. BUTLER (Marton, Yorks) expressed his thanks to the author for his very excellent paper on this important subject. There

was one feature in connection with gas cleaning which he thought might have been brought out in the paper, namely, that it would probably be necessary to thoroughly clean the whole of the blast-furnace gas when the point was reached in future development of utilising this gas for coke-oven heating. Personally, until the last year or two, he had been rather against the Halberg-Beth process, but he was rapidly altering his opinions, especially in view of the possible development just referred to, as it was probable that the Halberg-Beth process might be the most suitable for the purpose.

With regard to the Kling Weidlein, he must say that on his own plant it was giving fairly good results, and without it they would certainly have been in a very much worse position than that which they in fact occupied to-day.

He thought one of the most striking things with regard to the present-day attitude towards gas cleaning was that nearly everybody was looking for one particular type of cleaner that would do everything. He considered that was a mistake, and that the only satisfactory system of cleaning the whole of the gas produced at a blast-furnace plant for its economical utilisation throughout the different departments of a works was to do it in stages. For instance, the ordinary dust catcher attached to the furnace in conjunction with a primary dry-cleaning plant was sufficient for stoves and boilers. For this purpose he did not think it was necessary to go below 0.5 grm. per cu. m., and, in his opinion, 1 grm. was perfectly satisfactory. It depended on how one laid out one's plant. If one put down overhead gas mains from the dust catcher to the primary cleaner and from the primary cleaner through to the stoves and boilers, designing these mains with continuous bottom cleaning doors, there was no necessity to clean down further than 1 grm. at the primary cleaner. The bulk of the dust under 1 grm. would be deposited in the main between the primary cleaner and the stoves and boilers, and this main could be cleaned out daily whilst the plant was working; there would be no necessity to stop it for flue-cleaning purposes, except at very long intervals. It was a cheaper proposition to recover the dust below 1 grm. in this way than to use power at a cleaner to clean the gas down to the very fine degree required by gas engines. If one also used with this system a tower something like the Zschocke, combined with a Theisen disintegrator washer for gas-engine purposes, one would get, in his opinion, the most economical type of gas-cleaning plant. It was not necessary to clean the whole of the gas down to the limit of cleanliness required by gas engines. After all, one was not in business making pig iron in order to put in fancy gas-cleaning arrangements; the object was to make money, and it was the financial and economic side of the matter which had to be considered as being the main factor.

Mr. D. SILLARS (Middlesbrough) congratulated the author on a very valuable paper covering the most recent practice in gas cleaning.

Like other speakers, he highly approved of the Halberg-Beth process ; its only disadvantage was its price. It was the most satisfactory arrangement for removing the whole of the dust, but whether that was also the most economical arrangement was another matter. He did not think for a moment that rough-cleaned gas, in the sense in which the last speaker spoke of it, was at all satisfactory. There was no doubt that gas cleaned to any extent at all would give improved results, and it was possible that in some places one could not carry on without some rather elaborate form of primary cleaning ; in such cases even such an arrangement as the dry cleaner might form a very satisfactory solution to an immediate difficulty.

In this country, where the dust was usually rather fine, he did not think it was satisfactory. Those who had experience of gas at 1 grm. going through long mains to stoves would certainly agree that those stoves would need cleaning, and the extra cost of cleaning down to somewhere about 0.1 or 0.2 grm. would entirely cut out the cost of stove cleaning.

There was one point on which he thought the author had not laid the emphasis it required. In the wet-washing process it was very necessary, after the gas was cooled and cleaned, to remove the water ; the gas would carry for great distances large quantities of very fine spray, and he thought the necessity for very adequately separating not merely the water vapour, which was a function of temperature, but the actual water mist should be emphasised. That problem had only been solved by the use of very large separating vessels, which could not be considered a final solution.

He wished to mention a plant to which the author had not referred ; he thought it was the only one of its kind in existence, and would like to know more about it. It was based upon the Walther Feld gas cleaner, which was very well known in this country in gasworks for taking sulphuretted hydrogen out of the gas by the washing method. That plant was made only in small units in this country. There was, however, one very large unit in America, about which he thought a great deal more would be heard. The machine consisted of one central shaft, on which was mounted a number of discs ; the latter were rotated by the shaft, and a thin film of water was created by the centrifugal action of the machine on water running over the discs. He understood that the machine was giving excellent results and giving them in one apparatus, the cooling and cleaning being done together, without a cooler. There was no difference in principle between the plant used for blast-furnace gas and that hitherto used for the relatively small quantities of distillation gas, beyond the fact that the tower was divided into five or six different sections, each section being separately driven, instead of having an arrangement like the old type, where one long shaft drove the whole tower from top to bottom. A very important fact with that type of cleaner was that the power consumed was very low.

Mr. T. E. HOLGATE (Darwen) congratulated the author on his excellent paper. He wished to say one or two words with regard to his experience with an electrical plant of the pipe-treater type under somewhat unusual conditions. The problem which had to be faced was to purify the gases from a furnace making ferro-manganese, of which the temperature was anything from 1000° to 1200° F., and the dust contents 10 or 12 grm. per cu. m., the dust being in a finely divided state, more like fume than ordinary dust. On inquiring about the different methods, it was found that the water supply required for the washing process was beyond what could be provided. The temperature of the gases, which would need to be reduced very greatly for the Halberg-Beth process, rendered the use of that process impossible. On further inquiry, both in this country and in America, with regard to the Kling Weidlein process, it was considered that that process was not very satisfactory; some of its mechanical parts seemed to give trouble, and it appeared likely that unless the gases were cooled the high temperature would also cause trouble. Thus, only the electrical process was left, and on inquiring about that it was found that it did seem to be efficient and applicable. That type of plant was installed at a cost of over £30,000. On operation it was found that it cleaned the gases very satisfactorily, but other difficulties arose. The noise from the rapping of the pipes was very troublesome, particularly at night; residents, even a mile away, complained, and his firm was threatened with an injunction. Not long afterwards, however, the plant had to be shut down, like many others in the present depressed times.

Professor C. H. DESCH, F.R.S. (Member of Council), said one great difficulty with the electrostatic method of cleaning was the extremely high potential, which led to insulation difficulties and so on. He would like to know if the author had any experience of electrostatic cleaning at considerably lower voltages than those ordinarily employed, and whether that had yet been tried with blast-furnace gas. He believed that in some cement works new electrostatic plants had been installed which worked at a considerably lower voltage than was originally used; in that case there would be a reduction in the cost of the electrostatic plant, and at the same time insulation difficulties would become less severe. He believed the type of which he spoke did not involve the rapping which the last speaker had mentioned as being so objectionable.

Mr. F. BAINBRIDGE (Skinningrove) remarked that on p. 237 the author stated: "It is a matter for the management to decide at which point the benefits obtained from additional cleaning become no longer economical." From what Mr. Butler had said, it seemed that he considered that from 0.5 to 1.0 grm. was sufficient. Before putting down a plant for gas cleaning one needed to be very careful

in considering the type of dust which had to be dealt with. At his own plant there was present a large amount of dust of very high water-soluble alkali content in the form of chloride, and when operating the electrostatic plant it was found that of the gramme which was left in the semi-clean gas somewhere about 75 per cent. was alkali fume. He had also a Zschocke type of washer making a preliminary washing of the gas, also down to 1 gm., for another purpose, and on examining that dust after leaving this preliminary washer only some 30 to 35 per cent. of soluble alkali was found. That had a very important bearing when considering the use of semi-clean gas for stoves, because 1 gm. with about 75 per cent. of alkali coming forward to the stoves would almost completely glaze the brickwork in a week or two, and one would lose about 50 per cent. of the so-called cleaned gas efficiency, if not more. That point should be borne in mind.

In column 7 of Table I. the average dust content in clean gas in grammes per cubic metre was given, and it would be interesting to know to what temperature those figures referred, and whether they were all on one common basis. He was getting some information a considerable time ago at a plant which was cleaning gas by a process in which the gas left the plant at some 200° to 250° C., and the man who gave the guarantee insisted on calculating his dust content per cubic metre of the gas back to 250° C.; that, he (Mr. Bainbridge) thought, was very misleading, as it meant that if one cleaned down to 0.4 gm. nominally on this basis, one was actually only cleaning down to about 0.8 gm. cold. Since it was unusual to calculate any gas data, such as calorific values, on any other basis than 0° or 15° C., they all ought to be brought to a common standard; otherwise the cool gas plant was put in an unfavourable position on paper, though in actual practice it might be very much better.

Mr. J. A. SMEETON (London) said he was glad that iron and steel works were still interested in gas cleaning, and were still investigating the advisability of installing such plants; the Continent had fully explored the subject for 25 years. He quite agreed with Mr. Simons' opinion; there could be no question but that all the gas must be cleaned absolutely thoroughly if one were to get the highest efficiency from it. The question of the cost of the plant depended entirely on the return obtained from it. If the gas were cleaned in the dry Halberg-Beth plant down to 0.002 gm. per cu. m., such gas fed into boilers, Cowper stoves, industrial furnaces, or gas engines would yield the highest possible efficiency and economy. It would save a considerable amount of money which would otherwise be spent in cleaning the boilers, gas mains, stoves, and other parts of the plant in which the gas was used. It had always been a matter of surprise that works spending large sums of money on expensive gas engines should grudge the slightly extra first cost for perfectly cleaning the gas.

He knew of a works in the Midlands where the only means of cleaning

the gas consisted of a number of small dust-catchers spaced about 3 ft. apart along the large gas main, which was 150 to 200 ft. long. A large horizontal gas engine had been installed, but it had never run satisfactorily, and after about a year it was replaced by steam turbines. Somebody deserved severe censure for such a waste of money; it was also astonishing that the maker of the gas engine should have attempted to run it without first securing a supply of suitably cleaned gas.

CORRESPONDENCE.

MESSRS. FRASER and CHALMERS (London) wrote: There are several points to which one would like to draw attention. With regard to Plant IX., the bags are shaken not hourly, but every seven minutes. The figure 0.025 grm. per cu. m. for the dust content of the cleaned gas is higher than is ever obtained from an efficient plant properly operated. The usual figure is under 0.005 grm. per cu. m. The water-spraying tower referred to is a cooling tower, not an additional cleaner. As a result of cooling, condensed moisture separates out from the gas, and is removed by means of a tower packed with wooden grids. It is possible that a slight amount of dust might be entrapped by the moisture, but this would be quite fortuitous. The gas is already cleaned by the bags, as stated above, to a figure low enough for use in gas engines.

It is stated of Plant X. that "the cleaned gas on leaving contains from 0.1 to 0.2 grm. of dust per cu. m., although some tests show a much higher figure." Such a high figure could be due either to the use of exceptionally porous bags (that is, bags much more open than those normally specified for these plants), or by leaving in bags after they are broken. That the latter condition does obtain in this case is confirmed by the later statement that "under the conditions at these works it is more economical to get a longer life from the bags even at the expense of a somewhat less efficient cleaning of the gas." So long as a bag remains whole, its filtering properties tend to improve with age, but if "economies" are effected by leaving in bags after they are broken, then certainly more dust will pass through with the gas. What is really being done then is to by-pass a certain proportion of unfiltered gas through holes or slits (due to mechanical wear) in the bags. It is, however, incorrect in such a case to speak of the "longer life" of the bags. If a bag has a hole in it, it cannot be said to have a life unless it is repaired. The conclusion one is bound to draw from the above statement is that this particular plant is not being used for the purpose for which it is intended.

If the gas is only to be cleaned down to 0.1 to 0.2 grm. per cu. m. or worse, the bag plant is unnecessary. Its function is to give really clean gas, thereby effecting real economies which pay for its extra

cost of installation. Incidentally, it is interesting to note that, according to Table I., columns 8, 10, 12, and 13, the total operating costs of Plant IX. are actually below those of Plant X., in spite of the fact that the latter is run so inefficiently for the sake of effecting "economies."

Mr. DAVID E. ROBERTS (Cardiff) wrote: The author has effectively dealt with a question of first importance to blast-furnace owners in this country—one to which their attention can be profitably drawn. The savings resulting from the proper cleaning of gas have been variously estimated, and are considerable. Dirty gas means ineffective combustion, inefficient brickwork reaction in the stoves, heavy expense for replacement, and wear and tear in stoves and boilers, together with the constant labour cost for cleaning. One often hears of coarse cleaning and fine cleaning, and some reference has been made to it in the discussion. The generally accepted view, that fine cleaning is necessary only for gas engines, and that any kind of cleaning will do for the stoves and boilers, is, in my opinion, not quite sound; all gas should be cleaned, and, in my view, thoroughly cleaned. It is the very fine fume that does the greatest damage to the checkers in the stoves by glazing the surfaces, thus interfering with the ready absorption of heat by the brickwork, and conversely the equally rapid dissipation which is necessary for efficient stove working. Further, small checkers cannot be used without clean gas.

It has always been a somewhat disappointing feature in my view that the more common methods of cleaning necessarily involve the preliminary cooling of the gases. The saving of heat is a natural ambition of all engineers, and therefore on the face of it, it does appear to be wrong to permit the waste of say 300° to 400° F. or even more during the time the gas is being prepared for cleaning. For that reason the electrical arrangement seemed an attractive proposition, as it appeared at first to offer some chance of cleaning without cooling. Unfortunately, however, experience has shown that this is not the case, and that even with the electrical method the gas must be allowed to partially cool down before effective separation can go on. It is found at high temperatures that the fume adheres to the electrodes and somewhat insulates them, thus interfering with their usefulness. That being the case, and as this method does not seem to be able to clean *hot* gas any better than the others, I personally do not continue to have any great leaning towards it, as it is a little complicated.

The water system of towers, scrubbers, sprays, &c., has been in use for a good long time, and has come to be regarded as the most suitable, simple, and reliable method of cleaning, particularly when a disintegrator such as the Theisen washer is added to it. Long practice, however, has shown that the results are not consistently as good as was originally thought. The insides of gas engines, for instance, show that considerable quantities of fume get through, and it is to-day

believed by some people who have studied this matter that in a heavily laden gas some of the fine fume will get through any water device. In connection with these various water methods, much work has been done and some excellent material written by Deihl, who has for many years been connected with the Carnegie Co., Pittsburg. Most of the water-towers and other devices to-day are merely imitations of his ideas and of those of Zschocke and others.

The wet method, however, has many advantages: It is a fairly simple arrangement and is free from complications, and no great skill is necessary to operate it. It is not free from expense, however: as the quantity of water necessary is heavy, a good deal of pumping is involved, and in certain localities there is also some difficulty in the disposal of the dirty water and sludge after treatment. These have been overcome to a certain extent by various forms of settling tanks or thickeners, but the fact still remains that the dirty water has to be very carefully treated, and the water supply itself is no small matter. The Germans, who are very advanced in this matter of gas cleaning, were for years great supporters of this system of cleaning by water towers coupled to the Theisen fan, but their views on the subject seem to have undergone a considerable change during the last few years. They pin their faith now very largely to the Halberg-Beth arrangement, which is being used in increasing numbers and seemingly with general satisfaction. No trouble is experienced there in the running of this plant; each unit is under perfect control, and the running costs are less than with any other form of cleaner. The first cost is somewhat higher, but the cleaning is thorough, and figures of 0.001 grm. per cu. m. and even better are the regular thing. I have put down in the past more than one Halberg-Beth plant, but have never been in love with the method because the plant is expensive and the fabric bag is a somewhat delicate material. German engineers are insistent that no troubles should arise, that the plant is exceedingly easy to control, and cheap to run. Objection is sometimes made to the Halberg-Beth system being coupled to a single blast-furnace plant. One is inclined to agree that there are certain difficulties, but they are more imaginary than real, and this system has frequently been applied to a single furnace, not only abroad but in this country also, with satisfactory results. There is no fundamental difficulty; success is only a matter of proper control. In my opinion, the fabric stocking of the Halberg-Beth method is the only one that to-day will clean gas with absolute thoroughness. On the other hand, it must be admitted that more care is necessary in its control, especially when attached to one furnace. The old water system is simpler to handle and cheaper to install, and where gas engines are not in use is probably good enough for all ordinary purposes if the usual disintegrator is added.

Mr. V. HARBORD, in reply, said he quite agreed with Mr. Simons as to the unsatisfactory nature of the Kling Weidlein cleaner; in fact,

he had considered not saying so much about it in the paper, but he found that several had been installed in this country, so he decided that information regarding that system should be put on record for purposes of comparison. It would be noticed, however, that when the results and final costs were compared he had had to ignore the Kling Weidlein cleaner, because its results were not good enough for it to be considered as an efficient cleaner.

The question raised by Mr. Butler, whether one had to clean the whole of the gas and do it all at once, or whether one could do it in stages and by-pass gas with a certain dust content to the stoves, was one which everyone must decide for himself, taking into account the particular plant, the cost for which it could be done, and whether it would pay under particular conditions. In that connection he thought the remarks made by Mr. Bainbridge on the alkali content of the dust were extremely important. Dry cleaning, of course, did not generally remove so much of the soluble alkali, and that was undoubtedly the most harmful form of dust for brickwork.

Mr. Butler mentioned that since he had had his cleaner at work he had been able greatly to improve his furnace practice. That was only to be expected; the question was whether he would not have got much better results if he had carried his cleaning further. Mr. Butler mentioned 0.5 to 1.0 grm. for use in a stove, but he would see from the Kling Weidlein figures that that was very seldom achieved in the actual results recorded. One had to have a fairly costly installation to get down to that figure, and it might almost pay one to go the whole way and put in a complete cleaning plant.

Mr. Sillars raised an interesting point in remarking on water vapour being carried mechanically along with the gas. That was a matter to which possibly sufficient attention was not drawn in the paper, and it was certainly very important. In that connection he wished to say that the engineer of one particular works which he visited told him that they had found that the dust content of the cleaned gas was very different if they took the sample a short way farther along the main, where the mechanically carried mist had had time to settle, and the gas had lost that portion of its moisture. The dust content was very much lower. They considered it was the mechanically carried moisture which carried that dust on, and when that moisture was got rid of, the dust content was very much lower.

The new plant referred to by Mr. Sillars was of considerable interest, and he would like to have further particulars. The paper, of course, attempted to cover only those plants which were in actual operation in this country; he had not recorded results obtained with plants which he had not seen. Mr. Holgate's remarks on the ferro-manganese furnace were very interesting. He believed one of the old plants recorded in the paper was working at one time on a ferro-manganese furnace and gave very satisfactory cleaning.

He was afraid he could not give Professor Desch any information about low-voltage cleaning as he had not heard of any works in this country working on those lines, but if it were successful in cement works he had no doubt Messrs. Lodge Cottrell would thrash out the question with a view to applying it to blast-furnace work.

In reply to Mr. Bainbridge, the dust contents in clean gases were on a sufficiently common basis as regards temperature, as in all cases they were either corrected to N.T.P. conditions or were at ordinary atmospheric temperatures. Such slight variations would make no appreciable difference, but in no case were figures given based on temperatures varying to the extent mentioned by Mr. Bainbridge.

He (Mr. Harbord) noted Messrs. Fraser and Chalmers' remarks as to the shaking period for the bags in Plant IX. Regarding the figures given for the dust content of the gas, he did not in any way doubt that better figures for gas cleaning could be, and had been, obtained under the best operating conditions, but the figures given were those actually obtained over a prolonged period under normal working conditions without special maintenance or supervision. The works at which Plant IX. was operating was, in his opinion, one of the most efficiently managed and up-to-date plants in the country, and the conditions under which the cleaner was operating were probably as good or better than would be met with in many iron and steel plants. As to whether the tower referred to was primarily a cooling tower or a cleaner did not appear to be important, the fact remaining that during that stage of operations the dust content was lowered from 0.025 grm. to about 0.003 grm. per cu. m.

He quite agreed that Plant X. was not working as efficiently as it should have been from a gas-cleaning point of view. As explained in the paper on p. 249, it was originally installed with a view to potash recovery, but that was not being carried out at present, the gas being required only for stoves and boilers. He fully appreciated that a certain amount of gas was being by-passed through defects in the bags, but provided that the gas was sufficiently clean for the purpose for which it was required it might be economical to use the bags longer, even if less perfect cleaning were obtained.

With regard to the last remark of Messrs. Fraser and Chalmers, he would point out that in column 11, Table I., the repairs, stores, renewals, &c., per 1000 cu. ft., including the cost of bags, was more than three times as great in the case of Plant IX. as in Plant X. That was very largely due to the greater number of bags required in the former case in order to keep the dust content down even to the figure of 0.025 grm., which was not considered to represent efficient operation of the plant. To what extent that item would be increased to obtain a continuous figure of less than 0.005 grm. of dust per cu. m. under ordinary works conditions was an open question, but it seemed to him that it was doubtful whether one would be repaid for the extra expenditure, when the gas was only required for stove and boiler purposes.

The author thanked Mr. Roberts for his very interesting and concise résumé of the various points in favour of and against the different methods employed for gas cleaning. Mr. Roberts raised the question of the advisability, if possible, of cleaning the gas without previously cooling, with a view to saving the sensible heat therein; but even if a satisfactory method were devised, it was doubtful whether the saving would be so great as might be expected, as the cooling of the gas below the dew-point would cause the water vapour carried over in the gas to be deposited, which would tend to retard combustion in the stoves and boilers. There was no doubt that the Halberg-Beth process was really the most efficient one, but the bags required constant attention to maintain a low dust content, and the life of the bags was not very great. It was an interesting point that in the two examples of Halberg-Beth plants given in the paper, the item for repairs, renewals, &c., in column 2 of Table I. was three times as high for the plant where the cleaning was being carried down to 0.025 grm. per cu. m. as it was in the other case where the cleaning was only to 0.1 grm. per cu. m. That difference was almost entirely due to the more frequent bag renewals necessary to obtain the cleaner gas. The cost of bags and the high initial cost of the plant were the main drawbacks to the Halberg-Beth method of cleaning.

THE FATIGUE-RESISTING PROPERTIES OF 0·17 PER CENT. CARBON STEEL AT DIFFERENT TEMPERATURES AND AT DIFFERENT MEAN TENSILE STRESSES.*

By H. J. TAPSELL, A.C.G.I. (NATIONAL PHYSICAL LABORATORY).

ABSTRACT.

A review of the behaviour of a mild steel under fatigue stresses over a practical range of temperatures has been attempted. It is based on fatigue experiments carried out at the National Physical Laboratory on normalised 0·17 per cent. carbon steel, in order to obtain information concerning the effect on the fatigue limit due to a variation of the mean stress in a tensile direction.

The experiments were carried out in a Haigh machine under direct pulsating stresses, applied at the rate of 2400 cycles per minute. Fatigue limits were determined at different mean tensile stresses and at temperatures up to 500° C., the limits being based on endurance of 10^7 cycles. It has been shown that the practical use of the results obtained depends on their correct interpretation. For such an interpretation a knowledge of the yield points and of the limiting creep stresses at different temperatures is necessary. This information is given in the paper, and from the results of the experiments made it has been possible to correlate the factors concerned in the fatigue behaviour of the steel at high temperatures.

INTRODUCTION.

THERE is little published information relating to the fatigue-resisting properties of steel at high temperatures. Unwin⁽¹⁾ conducted some tests at a temperature of 200° C. and found that "the hot bars stood variations of stress rather better than the cold ones." Lea and Bugden,⁽²⁾ and Moore and Jasper,⁽³⁾ have published the results of investigations on the fatigue limits at high temperatures of some metals under conditions of reversed stresses (equal plus and minus stresses with zero mean stress),

* Received August 3, 1927.

and similar tests have been carried out at the National Physical Laboratory ⁽⁴⁾ in connection with a series of tests on metals at high temperatures made for the British Non-Ferrous Metals Research Association and the Engineering Co-ordinating Research Board of the Department of Scientific and Industrial Research.

The results obtained by the above investigators are in agreement, and show that the fatigue limits for low-carbon steels are considerably higher in the neighbourhood of 400° C. than at air temperature.

In the majority of machines and structures subjected to cycles of stress the mean stresses of the cycles are usually not zero, but have tensile values. It is therefore important to have information concerning the effect on the fatigue limit of a variation of the mean stress in a tensile direction, and also to consider the practical application of the results obtained at different temperatures.

The results given by Lea and Bugden ⁽²⁾ include an investigation, made on 0.14 per cent. carbon steel in a Haigh fatigue testing machine at 2000 cycles per minute, of the effect of a variation of the mean stress at high temperatures. The results indicate that the speed of reversal in fatigue tests at high temperatures has an important effect on the endurance in terms of "cycles to fracture," due to the simultaneous creeping which occurs at high temperatures when the superior limit of stress is high. They show that large ranges of stress at 400° C. and 500° C. are possible for 10⁷ cycles on a carbon steel, without failure resulting when the cycles occur at 2000 per minute. They do not, however, indicate that the results obtained have limited application.

In order to estimate the *practical* fatigue limits for different temperatures it is necessary to correlate the results of tensile, creep, and fatigue tests at the specified temperatures. Further work on the subject appeared to be desirable, and the tests given in this paper were undertaken with this object in view.

DESCRIPTION OF TESTS.

The published work carried out at the National Physical Laboratory ⁽⁴⁾ includes a series of fatigue tests under reversed

stresses (equal plus and minus stresses with zero mean stress) on a 0.17 per cent. carbon steel (normalised). The further results given in this paper were obtained on the same steel. The material was in the form of 1-in. diameter rolled bars, and a chemical analysis gave the following composition :

	%
Carbon	0.174
Silicon	0.130
Sulphur	0.018
Phosphorus	0.025
Manganese	0.685
Nickel	0.061

Fatigue limits have been determined at three different mean tensile stresses at temperatures of 20° C., 100° C., 200° C., 300° C., 400° C., and 500° C.

The work at the National Physical Laboratory, to which reference has already been made, included determinations of the ordinary tensile properties and the limiting creep stresses at various temperatures, and reference is made to these results in the discussion of the further results given in this paper.

The fatigue tests were made in a Haigh alternating stress testing machine running at about 2400 cycles per minute, and, as is usual for the case of reversed stresses at air temperature, a basis of 10^7 alternations was adopted. This basis was used mainly as a means of comparison between the fatigue limits of the material at different mean stresses and temperatures, and it is shown later that endurances of 10^7 cycles do not indicate that at all temperatures safe ranges of stress have been applied.

An electric furnace was used for heating the test-pieces, and the temperatures were measured by means of a platinum/platinum-rhodium thermocouple attached to a millivoltmeter. The tensile mean stresses were applied by means of the pull exerted by the calibrated springs which were fitted to the Haigh machine.

The test-pieces were subjected to cycles of alternating direct stresses of the form $M \pm \frac{R}{2}$,

where M = mean stress of the cycle = $\frac{f_{\max.} + f_{\min.}}{2}$

R = range of stress = $f_{\max.} - f_{\min.}$

$f_{\max.}$ and $f_{\min.}$ are the superior and inferior limits of stress respectively.

The results of tests in which the mean stress was zero ($M = 0$, the first value of mean stress used) have already been reported,⁽⁴⁾ but are reproduced for comparison in the tables and figures below. The second value of the mean stress used was about one-half the limiting range of stress obtained for zero mean stress, *i.e.*

TABLE I.—*Results of Fatigue Tests.*

Range of Stress Applied. Tons per sq. in.	Endurance. Millions of Cycles.	Estimated Fatigue Limit based on 10^7 Cycles. Tons per sq. in.
<i>Air Temperature.</i>		
...	...	0 ± 12.5
9.0 ± 9.0	11.12 U	11 ± 11 (0 to 22)
11.0 ± 11.0	14.85 U	
11.7 ± 11.7	0.58 B	
11.4 ± 11.4	0.92 B	
22.0 ± 4.0	11.10 U	22 ± 7.5 (14.5 to 29.5)
22.0 ± 5.5	12.00 U	
22.0 ± 7.5	11.12 U	
22.0 ± 8.1	0.01 B	
<i>Temperature, 100°C.</i>		
...	...	0 ± 12.3
11.0 ± 11.0	0.32 B	10.5 ± 10.5 (0 to 21.0)
10.0 ± 10.0	14.50 U	
10.5 ± 10.5	10.44 U	
21.0 ± 8.0	14.19 U	21 ± 8 (13 to 29)
21.0 ± 10.0	0.003 B	
21.0 ± 9.0	0.006 B	
<i>Temperature, 200°C.</i>		
...	...	± 12.3
10.5 ± 10.5	10.36 U	11.5 ± 11.5 (0 to 23)
11.5 ± 11.5	10.33 U	
13.5 ± 13.5	0.25 B	
12.5 ± 12.5	6.97 B	
12.0 ± 12.0	7.22 B	23 ± 11 (12 to 34)
23.0 ± 10.0	7.41 U	
23.0 ± 12.0	0.39 B	
23.0 ± 11.0	10.90 U	
23.0 ± 13.0	0.08 B	

U = unbroken. B = broken.

TABLE I. (*continued*).

Range of Stress Applied. Tons per sq. in.	Endurance. Millions of Cycles.	Estimated Fatigue Limit based on 10^7 Cycles. Tons per sq. in.
<i>Temperature, 300° C.</i>		
...	...	± 16.0
15.0 \pm 15.0	10.42 U	15 \pm 15 (0 to 30)
15.5 \pm 15.5	0.20 B	
16.0 \pm 16.0	0.16 B	
30.0 \pm 8.0	10.25 U	30 \pm 8 (22 to 38)
30.0 \pm 11.0	0.01 B	
30.0 \pm 9.0	0.02 B	
<i>Temperature, 400° C.</i>		
...	...	± 16.8
16.0 \pm 16.0	0.09 B	13 \pm 13 (0 to 26)
14.0 \pm 14.0	3.08 B	
13.0 \pm 13.0	10.17 U	
	32.38 B	
	(Test lasted about 10 days)	
24.0 \pm 6.0	19.22 B	24 \pm 6 (18 to 30)
24.0 \pm 8.0	(Test lasted about 5½ days) 0.01 B	
<i>Temperature, 500° C.</i>		
...	...	± 11.7
10.0 \pm 10.0	0.14 B	8.5 \pm 8.5 (0 to 17)
8.5 \pm 8.5	10.00 U	
9.25 \pm 9.25	1.00 B	
14.0 \pm 4.0	25.08 B	14 \pm 6 (8 to 20)
14.0 \pm 6.0	15.32 B	
	(10.00 U)	

U = unbroken. B = broken.

$\frac{1}{2}R_{M=0}$, and the third value was generally close to the zero mean stress range, *i.e.* $R_{M=0}$.

The results of the tests are given in Table I., and have been plotted in Figs. 1 to 4. In Figs. 1 to 3 the fatigue limits based on 10^7 cycles are plotted vertically against a base representing the mean stress. Information obtained from tensile and creep tests has been added to Table II., and to the figures to show the relation between the factors concerned. Fig. 4 has been constructed from information deduced from Figs. 1 to 3.

stress which the material will withstand for 10^7 alternations at 2400 cycles per minute.

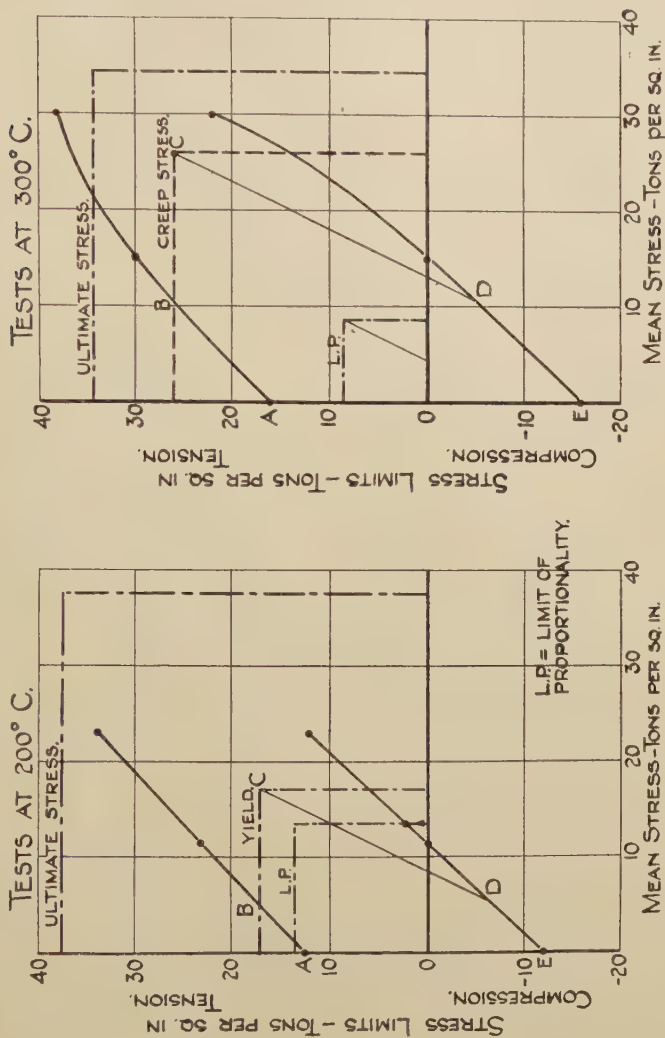


Fig. 2.

Although all the tests were carried out at a rate of 2400 cycles per minute, it seems evident that the rate at which alternations of stress are applied is of great importance, the endurance of the

steel at high temperatures being dependent on this rate. It has been found that at air temperature the rate of alternation has little, if any, effect on the endurance of a mild steel to reversed stresses (mean stress = 0). Whether it has any effect at air temperature on the endurance of such a steel subjected to ranges of stress having tensile mean values it is not possible to say at

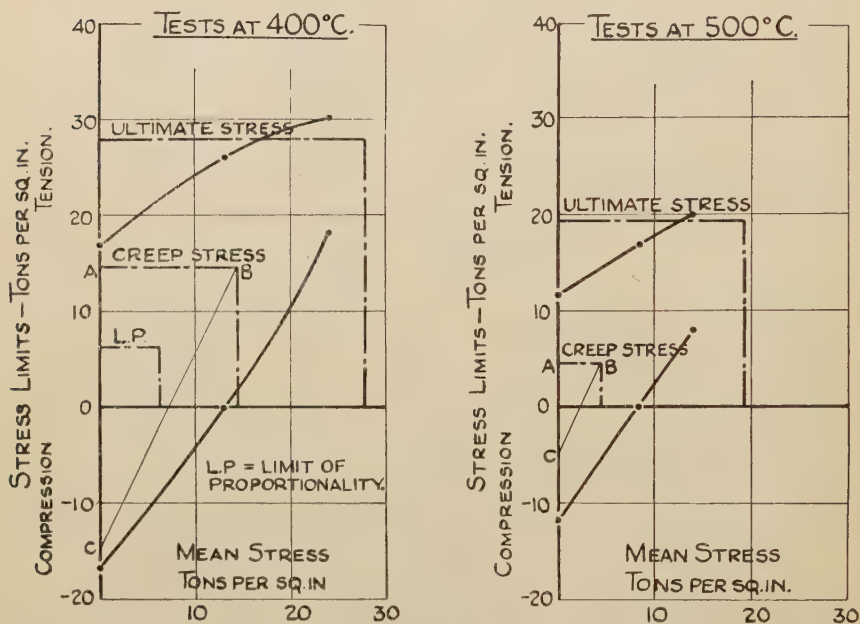


FIG. 3.

present. If the limiting creep stress for the 0.17 per cent. carbon steel at air temperature is less than the ultimate strength, then for high mean stresses the rate of alternations may have an important effect, although the mean stress in practice is rarely so high that the superior limit of the range approaches the ultimate strength of a material.

It will be seen from the figures that large ranges of stress can be applied at all temperatures even at high mean stresses, but it can safely be inferred that at the higher temperatures, where the creep stress is well below the ultimate strength, the 10^7 cycles of

stress have been carried out so rapidly that failure by creep has sometimes not had time to ensue.

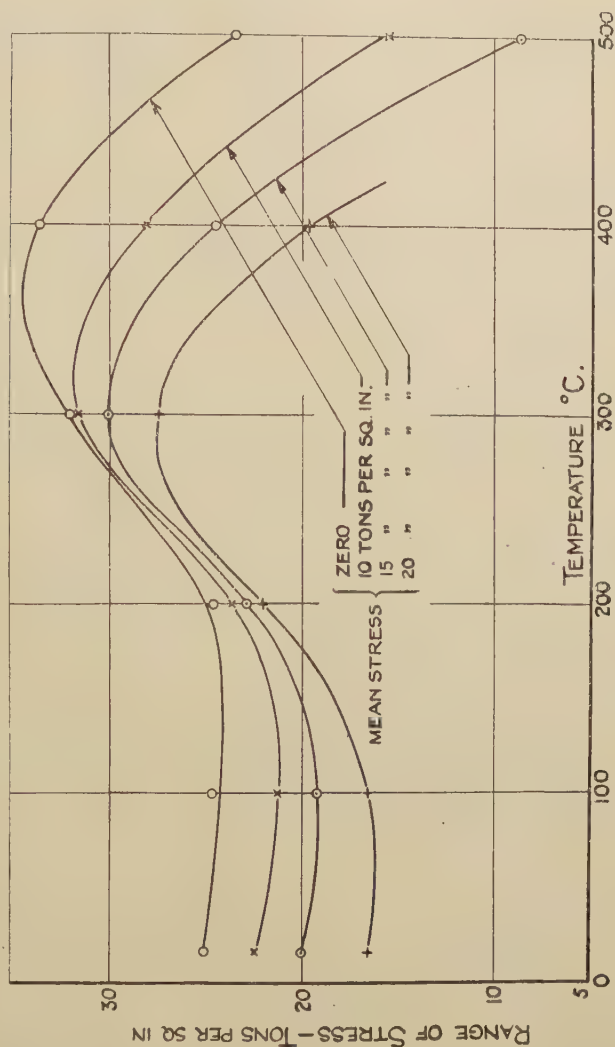


Fig. 4.

The superior limit of stress for alternations of stress applied at 2400 cycles per minute can apparently exceed the ordinary ultimate strength value of all temperatures. The results show this

TABLE II.—*Summary of Fatigue Test Results.*

Estimated Fatigue Limit. Tons per sq. in.	Ordinary Tensile Test Results.			Limiting Creep Stress. Tons per sq. in.
	Limit of Proportionality. Tons per sq. in.	Yield Stress. Tons per sq. in.	Ultimate Stress. Tons per sq. in.	
<i>Air Temperature.</i>				
0 ± 12.5 * 11 ± 11.0 * 22 ± 7.5	16.0	16.8	28.5	...
* In these cases the yield stress was exceeded, and permanent elongation resulted. The actual fatigue limits based on the reduced areas were 11.3 ± 11.3 and 26.2 ± 8.9 , instead of 11.0 ± 11.0 and 22.0 ± 7.5 tons per sq. in.				
<i>Temperature, 100° C.</i>				
0 ± 12.3 * 10.5 ± 10.5 * 21.0 ± 8.0	18.2	18.5	30.5	...
* The superior limit exceeded the yield stress. The actual fatigue limits based on the reduced areas were 10.95 ± 10.95 and 24.5 ± 9.3 , instead of 10.5 ± 10.5 and 21.0 ± 8.0 tons per sq. in.				
<i>Temperature, 200° C.</i>				
0 ± 12.3 * 11.5 ± 11.5 * 23.0 ± 11.0	13.5	17.1	37.6	...
* The yield stress was exceeded, and the actual fatigue limits based on the reduced areas were 12 ± 12 and 24.65 ± 11.75 , instead of 11.5 ± 11.5 and 23 ± 11 tons per sq. in.				
<i>Temperature, 300° C.</i>				
0 ± 16 15 ± 15 * 30 ± 8	8.6 ₅	...	34.3	26.0
* The mean stress of 30 tons per sq. in. exceeded the limiting creep stress of 26.0 tons per sq. in., and considerable elongation occurred in these tests, mainly during the first few hundred thousand cycles.				
<i>Temperature, 400° C.</i>				
0 ± 16.8 13 ± 13.0 * 24 ± 6.0	6.5	...	27.8	†14.5
* Test-pieces subjected to a mean stress of 24 tons per sq. in. broke with tensile (or creep) fractures. No sign of fatigue present.				
† Creep test-piece at 22 tons per sq. in. failed in less than 10 days.				
<i>Temperature, 500° C.</i>				
0 ± 11.7 8.5 ± 8.5 * 14.0 ± 6.0	5.0	...	19.4	4 to 5
* Test-pieces subjected to a mean stress of 14 tons per sq. in. broke with tensile fractures. The machine had to be continually adjusted to take up the extension due to creep.				

for air temperature and for 300° C. and above, and the figures for 100° C. and 200° C. indicate that there is not likely to be an exception for this temperature range. This result is probably due, at the lower temperatures, to the strain-hardening produced. A tensile test carried out on one of the fatigue specimens which had withstood 22 ± 7.5 tons per sq. in. for 11.12×10^6 cycles at air temperature gave a result of 32.5 tons per sq. in. as the new ultimate strength, estimated on the original area, as compared with the original strength of 28.5 tons per sq. in.

It is stated in Table II. that, at the high temperatures, tensile or creep failures sometimes occurred without signs of fatigue. There is no doubt that failure would have occurred eventually in these cases had no range at all been applied, purely as a result of the mean stress applied. A failure, mainly by fatigue, took place at 300° C. at a mean stress of 30 tons per sq. in., but here again failure by creep would have occurred eventually had no superimposed range been applied.

If it be assumed that a 0.17 per cent. carbon steel will not be subjected to any range of stress at which appreciable permanent set occurs, then the superior stress limit must not exceed the yield point, if such exists. At temperatures above 250° C., where there is no definite yield point, some other criterion of permanent set, such as limit of proportionality or proof stress, must be adopted. Under these circumstances the ranges of stress possible will be usually well within the limits of safety. Considering the tests at air temperature, Fig. 1, the practical fatigue limits must be such that the yield stress is not exceeded. Where the mean stress equals the yield stress the practical fatigue limit is zero. It follows that a line CD (Fig. 1) can be drawn such that the tangent of the angle $BCD = 2$, and the area $ABCDE$ so obtained includes all the practical fatigue limits which can be read off as the vertical intercepts of this area at any chosen mean stress. Since the fatigue limits for zero and small values of tensile mean stress are almost identical, the parts AB , DE , of the figure must be at nearly 45° to the axis. It is possible, therefore, to construct an almost correct diagram of the practical fatigue limits of such a steel from a knowledge of the yield point and of the limits for reversed stresses. It will be seen from the figures that the practical fatigue limits remain almost unaltered up to at least 200° C.

Where the practical conditions are such that *no* permanent strain can be allowed to take effect, then the superior limit of stress must be kept below the elastic limit or limit of proportionality. To suit such cases the limit of proportionality should be substituted for the yield point in the above statement.

At temperatures at which a real yield point does not exist, then, as stated previously, a suitable proof stress might be used to take the place of the yield stress, provided that the proof stress is not greater than the limiting creep stress. Unfortunately, no measurements of proof stresses were made when the ordinary tensile tests were carried out on this steel.

Above 200° C. (perhaps below this temperature), while the practical fatigue limits may be determined by yield points or proof stresses, the safe ranges under conditions in which permanent set is allowable are apparently determined by the limiting creep stresses. These safe ranges are apparently included within the area *ABCDE* at 300° C. (Fig. 2), and within the area *ABC* at 400° C. and 500° C. (Fig. 3). This argument assumes that if the superior limit of stress exceeds the limiting creep stress, then creeping will commence and persist until fracture occurs. The life of the steel under these conditions might be expected to be considerably greater than the life of the same steel when subjected only to a steady stress of amount equal to the superior limit of fatigue stress.

There is the possibility that the creep stress may be raised by the cyclical changes occurring in a fatigue test. Understressing at air temperature under conditions of reversed stresses is known to raise the fatigue strength of a low-carbon steel, but it has yet to be shown whether the creep limit can be raised by any such means.

CONCLUSIONS.

On reviewing the results obtained the following general conclusions may be drawn :

1. At temperatures above 300° C. the fatigue limits, based on 10^7 alternations of stress, appear wholly dependent on the rate of alternations applied.

2. " Safe " ranges of stress can be applied at 2400 cycles per minute for 10^7 cycles, in which the superior limit of stress is greater

than the ultimate stress in tension. Such a range of stress although "safe" would not generally have practical application, owing to likely troubles arising from the yielding of the material.

3. At temperatures up to 200°C . or 250°C . the *practical* fatigue limits under different mean tensile stresses are dependent on the static limit of proportionality or yield point of the material for the temperature considered.

4. The *practical* fatigue limits do not alter appreciably for temperatures up to 200°C .

5. Above a temperature of about 200°C . (above which a true yield point is not discernible) the *practical* fatigue limits are dependent on a suitable proof stress, which takes the place of the yield point, or on the limit of proportionality.

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DISCUSSION.

Dr. W. H. HATFIELD (Member of Council) expressed his appreciation of the value of the author's work. He wished to refer not only to the paper which had just been presented, but to another paper entitled "Note on the 'Creep' of Armco Iron," which was published by the Department of Scientific and Industrial Research. Those two papers together gave quite a lot of data of a kind which was badly needed at the present time, in view of the state of mind of some engineers, caused by the manner in which creep studies had hitherto been put before them.

He thought the data in Mr. Tapsell's paper must obviously be accepted as representing facts. They would be found invaluable in building up ideas of the capacity of that class of material. In speaking of the fatigue ranges of his material at ordinary and at high temperatures, the author said that the stresses must have a definite relationship to the yield at ordinary temperatures, or to the limiting creep stress at high temperatures. He submitted that the author was, in fact, speaking of one and the same characteristic of the material, and the sooner everyone realised that, the sooner the whole position from the standpoint of the designing engineer would be clarified.

It did not seem to be appreciated as it ought to be, that fatigue failure was not obtained until the material had been stressed within the range at which its plastic deformation would take place. He thought the author would be the first to agree with that. Then the stress under which a steel would behave as at any rate a practically elastic body had to be determined in a ready manner. As he had pointed out in his own (Dr. Hatfield's) paper,¹ if a tensile test-piece of mild steel were prepared and a stress imposed on it somewhere in the plastic range, an immediate elastic extension and an immediate plastic deformation were obtained, but if the dimensions of that test-piece were carefully examined over a period of time it would be found that the whole of the effect of the stress was not taken up by the plastic deformation until quite a considerable time had elapsed. In other words, a definite creep was there taking place at ordinary temperatures in the very type of material with which the author was dealing.

In the same way, the author spoke of limiting creep stress at high temperatures. He (Dr. Hatfield) presumed the author really meant the yield of the temperatures of which he was speaking. After all, when one determined the yield point of a piece of steel one determined the stress on the material which produced plastic deformation. The

¹ This volume, pp. 573-594.

figure for this stress was dependent on the refinement of the terms in which the observation was made.

That brought him to another point. It was absolutely essential that some information should be provided as quickly as possible for the use of engineers, which would give them a value comparable to the yield value at ordinary temperatures, and which should have some relationship to the fatigue range of the material at those temperatures. In their laboratory they had done a lot of creep work, and were, of course, out to deal with the matter from the practical standpoint of the industry. They had therefore decided that it was useful to postulate that if a test were made on a piece of steel so as to obtain the stress which would not produce an extension exceeding 0.5 per cent. in the first 24 hrs., and, after the first 24 hrs., would cause no further measurable increase in the length of the parallel portion for the next 48 hrs., a value comparable with the yield point was obtained, of which one could appreciate the real value. It might be said that he was postulating conditions of tests which were impracticable, but that was not the case. In their laboratory many tests had been carried out in that particular field upon ordinary steel. The accuracy of measurement employed was 1 in 10,000. Such a method of testing would require perhaps a week for one specimen, and therefore it was pretty obvious it could hardly be used as a reception test. On the other hand, it was the kind of information which engineers must have concerning the response of those steels at high temperatures, and adequate numbers of tests such as he had described, correlated with the patient investigatory work such as the author was engaged on, should in the near future put the engineer in the position of knowing what factor of safety he should use with his material.

He did not claim that the conditions which he had postulated gave the elastic range of the material; they gave a value, however, which must have a relationship to the elastic range similar to that which the yield point had to the elastic range, and therefore the engineer knew approximately where he was.

Taking the 0.5 per cent. extension in the first 24 hrs., which must not be exceeded, and the absence of further extension over the next 48 hrs., and comparing wrought iron and mild steel, the amazing fact came out that for wrought iron the limiting creep or yield stress, such as he had just mentioned, was 6.6 tons at 400° C., while at 500° C. it fell to 3.2 tons. In the case of an open-hearth mild steel with a carbon content of 0.27 per cent., at 400° C. the value obtained was 12 tons and at 500° C. it was 6.9 tons. That showed an astonishing disparity of values between wrought iron and mild steel. With regard to both those values, however, it was quite clear—and this was the main point—that in obtaining a value at 400° C. the zone of temperature was entered for which an engineer must entirely reconsider his factors of safety.

In their own and other laboratories in Sheffield every attempt was being made systematically to provide the data required for steels at 1928—i.

high temperatures, and contributions of the kind which Mr. Tapsell had brought forward could not be welcomed too much.

Mr. T. P. COLCLOUGH (Rotherham) expressed his appreciation of the excellent work published in the paper, which was likely to be of fundamental importance in the development of material for the construction of plates for high-pressure boilers and similar duties. He asked whether it was possible for the author to continue his investigation on material in the form of rolled plate. Lloyds' engineers and the Admiralty engineers said that the 0.17 per cent. carbon steel specified in the paper had an elastic limit, or limit of proportionality, in the neighbourhood of 10 to 12 tons, and 12 to 14 tons for a 0.35 per cent. carbon steel. The elastic limit given in the paper was considerably higher than that, with which he was in full agreement from his own experience. He had always found that the limit of proportionality in 1-in. rolled bars, such as the author had taken for investigation, was very close indeed to the yield point, but similar results were not obtained with material which was rolled into plate and had its work done more in the unilateral direction. Had the author any information on that point?

Another point of importance was that in the tests carried out on the 1-in. bars the reversals of stress had been at the rate of 40 a second. In the case of boiler work or structural steel the reversals of stress had nothing like that rapidity, and it would be of value to engineers and to manufacturers of the material if an idea could be given as to what those limiting stresses and reversals were when the stresses were applied at a very much slower rate.

Another point requiring careful investigation was the determination of the limiting stresses under reversal for material tested in a transverse section, as compared with a longitudinal section, in order to determine the effect of the "grain" or inclusions in the steel.

Dr. W. ROSENHAIN, F.R.S. (National Physical Laboratory), drew attention to the fact that endurance phenomena, of which resistance to fatigue and resistance to creep were examples, were now giving rise to the idea that they had a common factor. Much depended, of course, on the mechanism by which the metal underwent deformation and fracture, and that mechanism ultimately was not very different, apparently, in the different forms of failure; it depended perhaps most on the temperature and the rate of deformation to which the metal was subjected.

It was necessary, however, to exercise care. The view was being established that in fatigue testing at ordinary temperatures, at all events for iron and steel, definite fatigue limits could be assigned—in other words, that there were stresses which would not break the material however often reversed. In the same way, it was hoped that even at high temperatures there were stresses which, however long applied,

would not produce fracture or deformation sufficiently serious to be dangerous or to make the material useless. One did not really know as yet, however, whether that was so. In the case of certain non-ferrous metals it was to be feared that there was no true, safe limit of fatigue, and if that were the case with those metals at ordinary temperatures it might be anticipated it would be the case with ferrous metals at higher temperatures. The whole thing was a question of the relative temperature range.

The example Dr. Hatfield quoted of the disparity between wrought iron and mild steel, the mild steel being very much better at 400° C. and not very much better at 500° C., was capable of an explanation which he suggested quite tentatively in the present stage of our knowledge. It was that an "equivalent" temperature—the transformation or eutectoid temperature—which came in as regards mild steel, and only came in, perhaps, at A_3 in the case of the wrought iron, affected the position in the relative temperature scale of those two materials in a different way.

A whole series of investigations was throwing new light on the question of the endurance properties of metals. It had been shown recently that certain metals had a static endurance limit at ordinary temperatures; in other words, a stress above that limit which would not break them in two or three hours would break them in two or three months, or two or three years. The whole thing depended on a knowledge of the mechanism by which those long-time failures occurred, and one must beware of one factor there, which had recently been brought out clearly by the work of McAdam in America, namely, the influence of chemical agencies. McAdam called them corrosion, but, personally, he thought influences other than the ordinary corrosive influences might play a part in the matter.

One began to wonder whether, particularly in tests at high temperatures, the atmosphere in which those tests were carried out might not be important. That might have a much greater effect on some materials than on others.

Mr. TAPSELL, in reply, remarked that the results given in the paper were presented in order to draw attention to the characteristics of a particular material. He derived certain conclusions from the results, but it was not suggested that those conclusions applied to all materials.

Dr. Hatfield had suggested that the yield and the limiting creep stress might be virtually the same, but he could not agree. In the case of fatigue failure, he agreed there was always some plastic deformation taking place, and that probably, therefore, the limiting creep stress determined the superior limit of the fatigue range. However, the *practical* superior limit at air temperature would be the yield point in the manner which he had suggested in the paper, but Dr. Hatfield had postulated what really amounted to another definition for yield point, or rather, in order to determine a safe upper limit, he defined

what was equivalent to another yield point. In other words, Dr. Hatfield said that at the low temperatures he considered some stress intermediate between the limit of proportionality, and the yield point was a suitable one to adopt, and that was the value he obtained by the test in which he specified a 0.5 per cent. elongation within 24 hrs. and practically nothing for the next 48 hrs. The stress to which Dr. Hatfield referred was, therefore, neither what was

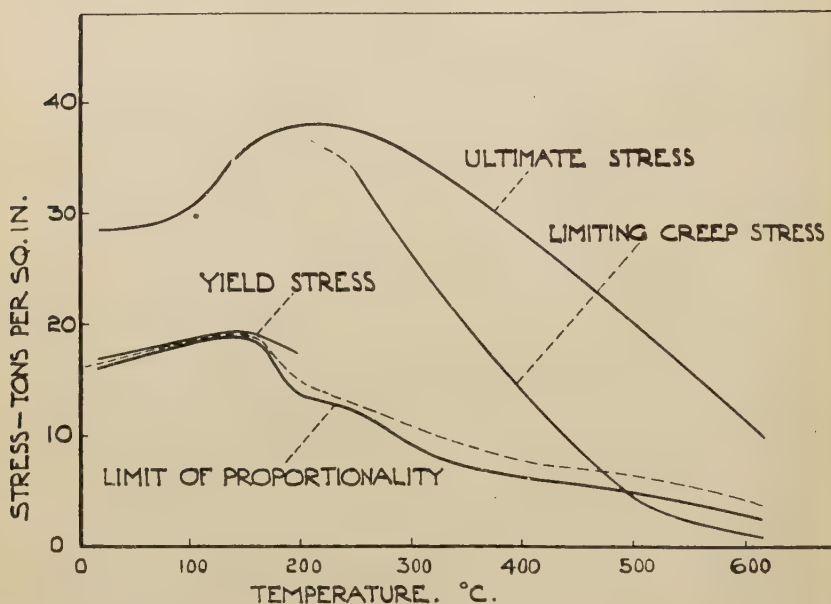


FIG. A.

ordinarily regarded as the limit of proportionality nor as the yield point, but some intermediate stress.

Similarly, what Dr. Hatfield was defining was something above the limiting creep stress at 500° C., so that the curve representing the stresses to which Dr. Hatfield referred would follow the curve shown by the dotted line in the diagram, Fig. A.

He had not tried Dr. Hatfield's method, but he was not sure that it would give satisfactory results, because, as he had shown in presenting the paper, there was very considerable elongation at the yield point at air temperature the moment the load was applied, and then a considerable elongation afterwards, whereas at or a little above the limiting creep stress at 500° C. the elongation at the moment of applying the load was extremely small, and the increase in the first day or two was also extremely small. At the higher temperatures there

was therefore a possibility that, by specifying a 0.5 per cent. elongation in the first 24 hrs., a stress would be obtained very much above the limiting creep stress as it was defined in the paper.

In answer to a question interposed by Dr. Hatfield, Mr. Tapsell said that the time required to produce the limiting creep stress under his (Mr. Tapsell's) method of testing was long; it might take three months or it might take five. When the limiting creep stress at 500° C. was reached (see Fig. A) the elongation at the start was practically all elastic. If one calculated roughly what it should be from the modulus, one found it was practically the elastic extension, and during the first few days there was practically no increased extension, so that by adopting the constant figure of 0.5 per cent. throughout the whole temperature range one might obtain a value considerably above the limiting creep stress at the higher temperatures. It was better to rely on the limit of proportionality and yield point, which could be determined within half a day, than to rely on some arbitrary stress between the limit of proportionality and the yield point, which took a long time to determine, and probably could not be obtained so accurately as the limit of proportionality.

With regard to the difference between wrought iron and mild steel, the differences between the materials, as quoted by Dr. Hatfield and as determined by his test, depended on the ductility above the limit of proportionality. It seemed to him that it was not always possible to use such a figure as 0.5 per cent. for any material in order to determine the practical value for the superior limit of fatigue stress, because it appeared to him that the figure would have to be varied according to the ductility of the material above the limit of proportionality.

In a written reply, Mr. Tapsell reminded Dr. Hatfield that, for the purpose of estimating the practical superior limit of fatigue stress he (Mr. Tapsell) had suggested the use of one of four determining factors—namely, limit of proportionality, proof stress, yield point, and limiting creep stress. Dr. Hatfield preferred to use, at all temperatures, a "value comparable with the yield point," which was equivalent to the proof stress suggested in the paper for certain ranges of temperature. In cases where, at air temperature, a definite yield point (as ordinarily understood) was absent or was much higher than the limit of proportionality, the determination and use of a proof stress might be advisable, in the same manner as was suggested in the paper for the intermediate temperatures.

In estimating the practical fatigue limits at air temperature, he thought it was doubtful whether any added advantage was to be gained from the use of a proof stress such as Dr. Hatfield suggested. Any stress above the elastic limit caused some creep, and it was a matter for the designing engineer to ascertain how much, if any, permanent set he could accommodate under the most adverse conditions. If the set which could be accommodated was considerable, then, for high mean stresses, the superior limit of fatigue stress at low as well as at high temperatures could apparently coincide with the

limiting creep stress, but whereas at high temperatures the amount of creep at the limiting creep stress was very small, it was excessive at low temperatures.

When considering the possible application of such a test as Dr. Hatfield had submitted, it should not be forgotten that for zero mean stress the fatigue limit of the material used in the tests was below the limit of proportionality. In addition, considerable understressing in fatigue had been shown to raise the fatigue limit of such a steel, and it was generally considered that there was no definite connection between the fatigue limit and the primitive value of the elastic limit.

From Dr. Hatfield's remarks it would be inferred that he (Dr. Hatfield) considered that the yield point, as he defined it, and the limiting creep stress were practically one and the same thing, but he did not think Dr. Hatfield really meant that. There was evidence to show that, at low temperatures, some steels had limiting creep stress values well in excess of the yield point. In the paper entitled "Note on the 'Creep' of Armco Iron" referred to by Dr. Hatfield, it was shown that the specimen of Armco iron which had been stressed above the yield point, but below the limiting creep stress, until all perceptible creep had ceased, finally reached a stage at which it became elastic up to the applied stress. Such a material was then strain and temperature hardened. It was in a different physical condition from its original normalised state, and appeared to be as stable as a rolled bar.

In reply to Mr. Colclough, he would state that the particular steel he used was in the normalised condition (after rolling), and it was characteristic of normalised low and medium carbon steels that they possessed yield points which were close to the limits of proportionality. With regard to the effect of the speed of reversals, he considered that it was extremely probable that, at any temperature, the practical fatigue limits, as defined in the paper, would be unaffected by slower applications of stress. Concerning the effect of grain direction upon the fatigue limits, he wished to refer Mr. Colclough to a recent paper¹ by Dr. R. M. Brown, in which it was shown that for annealed or lightly cold-drawn mild steel grain direction had no appreciable effect on the fatigue range.

He agreed with Dr. Rosenhain that fatigue and creep phenomena appeared to have a common factor. In carrying out the fatigue tests at the higher temperatures he was uncertain whether erratic results would be obtained due to corrosion or oxidation at the highest temperatures, but such oxidation did not prevent the application, for ten million cycles, of much larger ranges than were of practical utility.

¹ "An Investigation into Some Effects of Cold-Drawing on the Strength and Endurance of Mild Steel," *Paper read before the Institution of Engineers and Shipbuilders in Scotland*, Feb. 1928.

THE PROPERTIES OF NICKEL STEELS, WITH SPECIAL REFERENCE TO THE INFLUENCE OF MANGANESE.¹

By J. A. JONES, M.Sc. (WOOLWICH).

INTRODUCTION.

THE nickel steels have probably a wider industrial application than any other type of alloy steel, besides forming the basis of several systems of quaternary alloys of great importance.

There already exists a very extensive literature dealing with the properties of nickel steels, but the experimental study of these steels described in the present report serves to supplement existing information, and more particularly directs attention to certain effects produced by the presence of small quantities of manganese or chromium. It comprises determinations of (1) the critical ranges of a number of nickel steels, and the effect of manganese on the position of the critical points; (2) the effect of varying the rate of cooling of the steel on its hardness and microstructure; (3) comparative mechanical tests illustrating the effect of small quantities of manganese and of chromium; (4) the correct temperature limits of heat treatment; and (5) the influence of manganese and of chromium on the mass effect shown by nickel steels.

The steels examined in the first instance were crucible steels containing:

Carbon. %	Manganese. %	Nickel. %
0.3	0.25 and 0.8	3 to 10
0.2 to 0.55	0.35 „ 0.8	4
0.4	0.4 „ 0.8	3 to 8

For the purpose of making a further study of the effect of manganese in steels of selected nickel content, two series were added containing:

Carbon. %	Manganese. %	Nickel. %
0.4	0.1 to 0.95	4
0.4	0.2 „ 1.6	3

¹ Communication from the Research Department, Woolwich, received January 18, 1928.

TABLE I.—*Chemical Analyses of Steels Tested.*

Steel No.	R.D. Mark.	Carbon. %	Silicon. %	Manganese %	Sulphur. %	Phosphorus. %	Nickel. %
1	FNH	0.30	0.13	0.26	0.027	0.008	3.21
2	FNJ	0.29	0.15	0.25	0.027	0.009	4.32
3	FNK	0.30	0.13	0.28	0.030	0.015	5.22
4	FNL	0.30	0.13	0.28	0.023	0.014	6.22
5	FNM	0.28	0.12	0.26	0.020	0.015	8.24
6	FNF	0.31	0.12	0.25	0.020	0.008	10.12
7	GOG	0.28	0.10	0.84	0.024	0.022	3.00
8	GOH	0.31	0.09	0.86	0.036	0.022	4.00
9	GOJ	0.31	0.13	0.79	0.036	0.022	4.97
10	GOK	0.29	0.13	0.80	0.034	0.023	5.98
11	GOL	0.26	0.11	0.80	0.032	0.023	6.99
12	GOM	0.28	0.09	0.81	0.034	0.022	8.06
13	GLN	0.37	0.06	0.42	0.043	0.023	4.13
14	GNC	0.38	0.08	0.45	0.036	0.018	5.13
15	GND	0.41	0.07	0.44	0.033	0.019	6.07
16	GNE	0.40	0.07	0.45	0.036	0.019	7.16
17	GNF	0.39	0.07	0.43	0.035	0.018	8.06
18	GOQ	0.38	0.08	0.87	0.039	0.021	3.19
19	GOR	0.38	0.10	0.81	0.046	0.022	4.17
20	GOS	0.40	0.10	0.87	0.043	0.021	5.08
21	GOU	0.40	0.09	0.87	0.049	0.024	7.20
22	FNB	0.15	0.04	0.27	0.017	0.013	4.35
23	FNC	0.24	0.06	0.35	0.026	0.009	4.08
24	FND	0.31	0.05	0.36	0.018	0.010	4.10
25	FNE	0.43	0.08	0.40	0.020	0.009	4.28
26	FNG	0.56	0.07	0.45	0.018	0.009	4.26
27	GDR	0.21	0.08	0.81	0.040	0.018	4.05
28	GDS	0.33	0.08	0.80	0.042	0.018	4.12
29	GDT	0.47	0.07	0.81	0.039	0.020	4.17
30	GDU	0.55	0.07	0.84	0.039	0.019	4.15
31	OJ	0.40	0.06	0.09	0.040	0.020	3.81
32	OK	0.38	0.07	0.13	0.042	0.020	4.00
33	OL	0.39	0.07	0.32	0.042	0.020	3.76
34	OM	0.38	0.05	0.43	0.038	0.019	3.97
35	ON	0.41	0.05	0.56	0.038	0.018	3.94
36	OP	0.41	0.08	0.80	0.038	0.018	3.95
37	OQ	0.41	0.06	0.94	0.036	0.018	4.02
38	DCZ	0.42	0.15	0.17	0.036	0.021	3.09
39	DDA	0.39	0.08	0.60	0.016	0.026	2.98
40	DDB	0.34	0.10	0.83	0.018	0.027	3.00
41	DDC	0.43	0.15	1.60	0.017	0.028	2.96
42	GLO	0.40	0.06	0.45	0.047	0.022	4.12
43	GLP	0.39	0.06	0.44	0.046	0.019	Chromium 0.15 4.13 Chromium 0.22

The effect of small amounts of chromium was determined in three steels containing :

Carbon. %	Manganese. %	Nickel. %	Chromium. %
0.4	0.4	4	Nil to 0.2

The composition of the steels is shown in Table I.

CRITICAL RANGES.

Critical ranges were determined by means of a platinum/platinum-rhodium thermocouple and Carpenter-Stansfield poten-

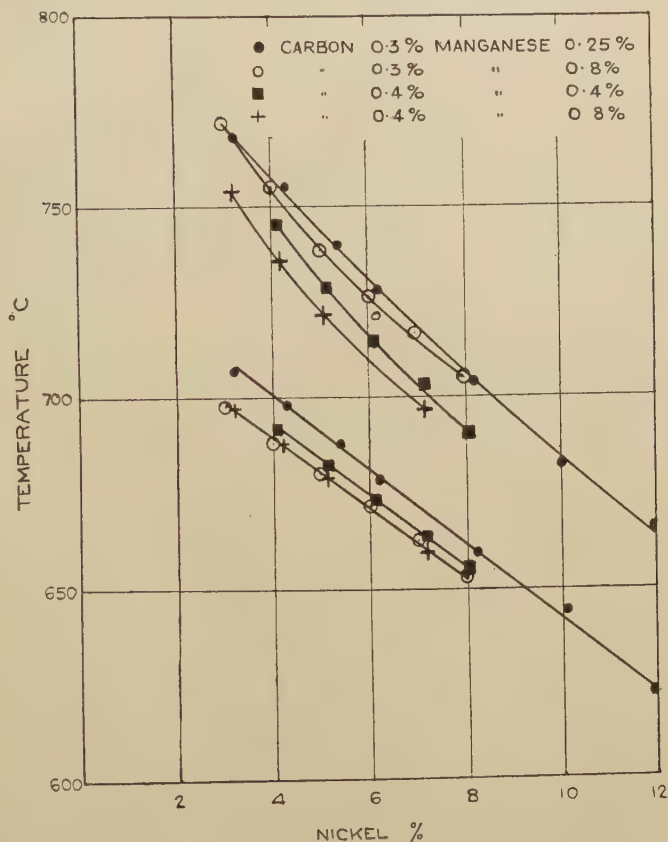


FIG. 1.—Critical Ranges. Effect of Nickel on Ac_1 (max.) and on Ac_3 (end).

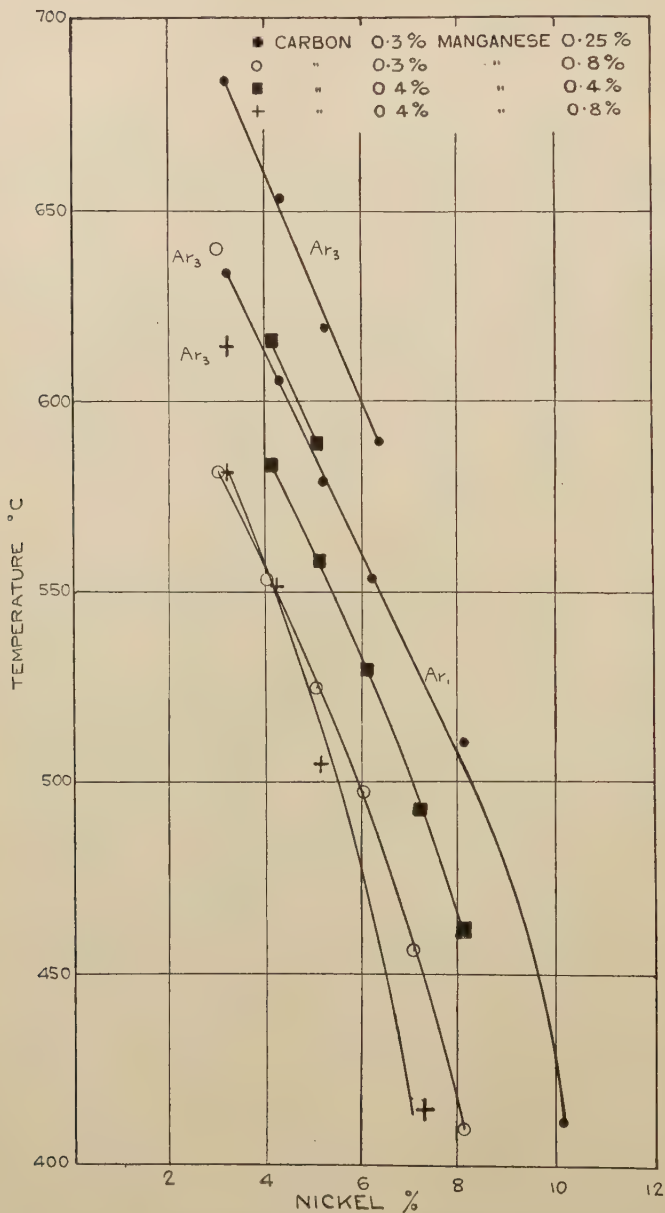


FIG. 2.—Critical Ranges. Effect of Nickel on Ar_3 (max.) and Ar_1 (max.).

tiometer, used in conjunction with a Rosenhain plotting chronograph. The rate of heating employed was 6° to 7° C.

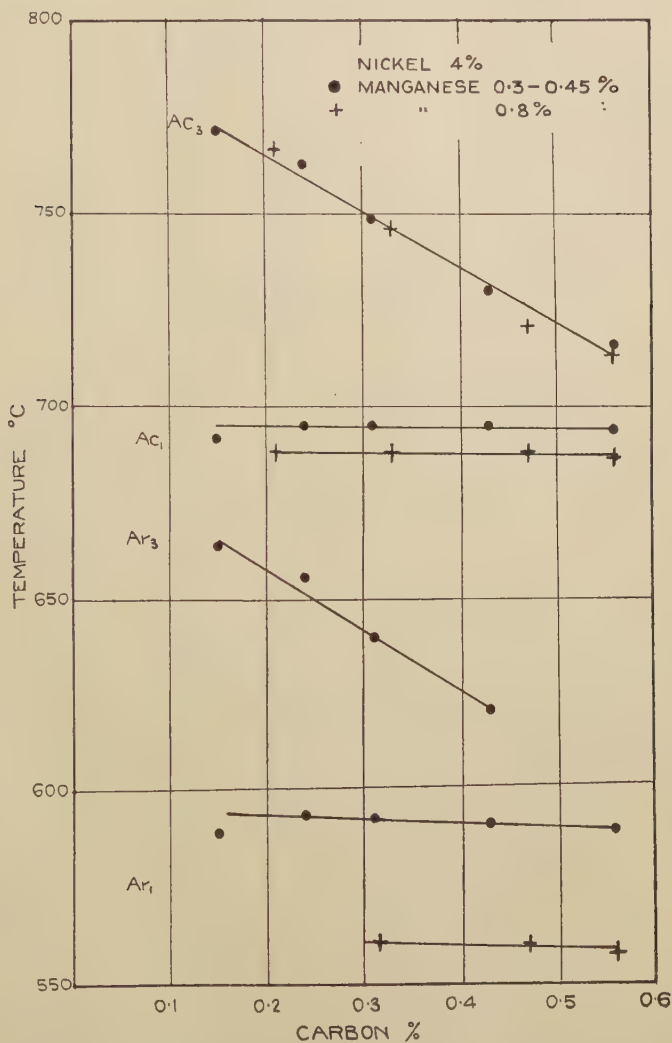


FIG. 3.—Critical Ranges. Effect of Carbon.

per minute below AC_1 , and the cooling rate was between $4\frac{1}{2}^{\circ}$ and $3\frac{1}{2}^{\circ}$ C. per minute above the critical range. Observations were not continued below 350° C.

Brinell hardness tests were made on the critical range cylinders after the cooling curves had been taken. Results are shown in

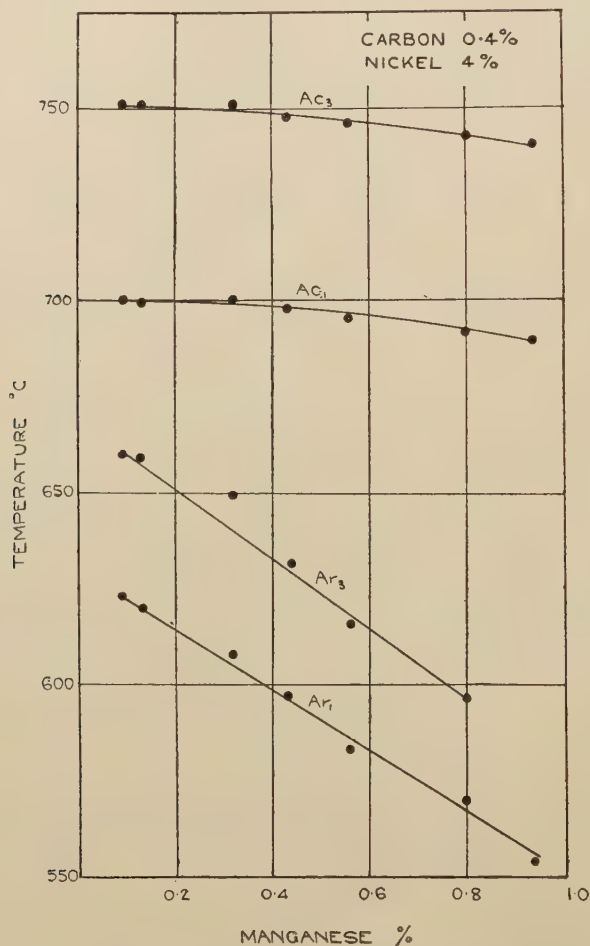


FIG. 4.—Critical Ranges. Effect of Manganese.

Figs. 1 to 4, and are given in detail in Table II. The figures indicating the effect of carbon and nickel content are in good agreement with those of Scott ⁽¹⁾ and Andrew, ⁽²⁾ and with previous determinations in the Research Department, Woolwich, ⁽³⁾ on steels containing up to 4 per cent. of nickel.

TABLE II.—Critical Ranges.

Steel No.	Carbon. %	Man-ganese. %	Nickel. %	Heating.		Cooling.			Average Brinell Hardness Number.
				Ac ₁ .		Ac ₃ End. ° C.	Ar ₃ Max. ° C.	Ar ₁ Max. ° C.	
				Begin-ning. ° C.	Max. ° C.				
1	0.30	0.26	3.21	695	707	768	684	629	153
2	0.29	0.25	4.32	689	698	756	655	606	162
3	0.30	0.28	5.22	677	688	741	619	579	176
4	0.30	0.28	6.22	668	678	728	590	554	186
5	0.28	0.26	8.24	648	659	704	...	511	208
6	0.31	0.25	10.12	631	644	682	...	412	321
...	0.21	0.18	12.03	610	623	666	...	...	413
7	0.28	0.84	3.00	691	698	773	641	582	169
8	0.31	0.86	4.00	679	688	756	...	554	189
9	0.31	0.79	4.97	672	681	739	...	525	208
10	0.29	0.80	5.98	664	672	727	...	498	232
11	0.26	0.80	6.99	654	663	718	...	457	262
12	0.28	0.81	8.06	645	653	707	...	410	307
13	0.37	0.42	4.13	680	691	746	620	584	176
14	0.38	0.45	5.13	669	682	729	589	558	188
15	0.41	0.44	6.07	659	673	715	...	530	212
16	0.40	0.45	7.16	650	664	704	...	492	226
17	0.39	0.43	8.06	643	654	689	...	462	250
18	0.38	0.87	3.19	689	697	754	620	583	189
19	0.38	0.81	4.17	677	688	737	...	553	200
20	0.40	0.87	5.08	668	679	722	...	505	232
21	0.40	0.87	7.20	648	659	697	...	415	328
22	0.15	0.27	4.35	683	692	772	664	589	137
23	0.24	0.35	4.08	682	695	763	656	594	154
24	0.31	0.36	4.10	679	695	748	640	593	159
25	0.43	0.40	4.28	679	695	730	621	592	177
26	0.56	0.45	4.26	679	694	716	...	590	204
27	0.21	0.81	4.05	680	688	767	Not observed		171
28	0.33	0.80	4.12	677	688	747	595	562	194
29	0.47	0.81	4.17	678	688	721	...	562	224
30	0.55	0.84	4.15	675	687	714	...	559	249
31	0.40	0.09	3.81	685	700	751	680	623	163
32	0.38	0.13	4.00	685	699	751	659	619	164
33	0.39	0.32	3.76	685	700	752	650	608	164
34	0.38	0.43	3.97	685	698	747	631	597	171
35	0.41	0.56	3.94	682	695	747	615	582	181
36	0.41	0.80	3.95	681	692	743	596	570	191
37	0.41	0.94	4.02	679	689	740	...	553	207
38	0.42	0.17	3.09	695	708	757	666	624	161
39	0.39	0.60	2.98	692	700	762	652	603	167
40	0.34	0.83	3.00	691	697	765	642	594	178
41	0.43	1.60	2.96	682	692	737	...	472	270
13	0.37	0.42	4.13	680	691	746	620	584	176
42	0.40	0.45	4.12	681	693	740	612	584	185

of the point as given by thermal curves, and also to the fact that a small variation from the standard rate of cooling often affects the position of the Ar points to a considerable extent. In considering the Ac_1 points, however, allowance need only be made for small accidental variations in composition.

From the results of the present investigation it may be concluded that in steels containing up to 12 per cent. of nickel the extent of the lowering of Ac_1 is approximately proportional to the increase in nickel content, and amounts to about $10^\circ C.$ for each 1 per cent. of nickel. The extent to which Ar_1 is lowered by nickel is dependent on the rate of cooling, and on the carbon and manganese contents of the steels. In steels containing 3 to 5 per cent. of nickel cooled from $850^\circ C.$ at about $4^\circ C.$ per minute, the approximate lowering of the Ar_1 point for each 1 per cent. of nickel is indicated below :

Carbon. %	Manganese. %	Ar_1 Point lowered by $^\circ C.$
0.30	0.25	25
0.30	0.80	28
0.40	0.40	27
0.40	0.80	30

The critical ranges of steels with increasing nickel content given in the "Seventh Report to the Alloys Research Committee" ⁽⁴⁾ should be regarded as definitely replaced by the more recent determinations referred to above. Manganese has no effect on Ac_1 and Ac_3 until about 0.3 per cent. is reached ; above 0.3 per cent. there appears to be a very slight lowering of both points. The critical range on cooling is continuously depressed by manganese, the effect on Ar_3 being slightly greater than on Ar_1 , as shown in Fig. 5. The effect of manganese is also illustrated in conjunction with that of carbon and nickel in Figs. 1 to 4.

The important temperatures in connection with heat treatment are those of the Ac_1 and Ac_3 points. To obtain efficient hardening the steel must be quenched after it has attained at every point a temperature above the end of Ac_3 , and the maximum temperature employed in the subsequent tempering must not exceed the beginning of the Ac_1 point. The position of the Ar points need not be considered in the choice of the minimum temperature of heating for hardening or the maximum temperature for tempering,

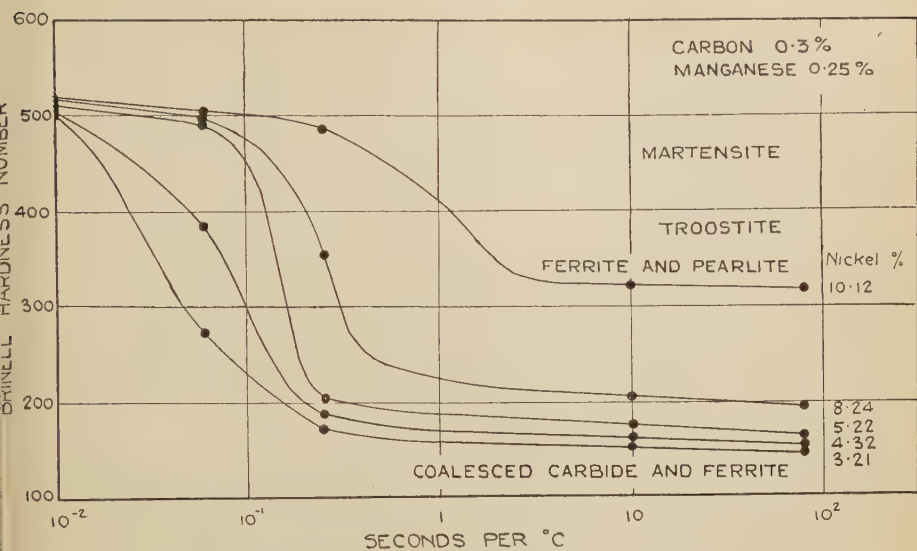


FIG. 5.—Hardness after Different Rates of Cooling. Effect of Nickel.

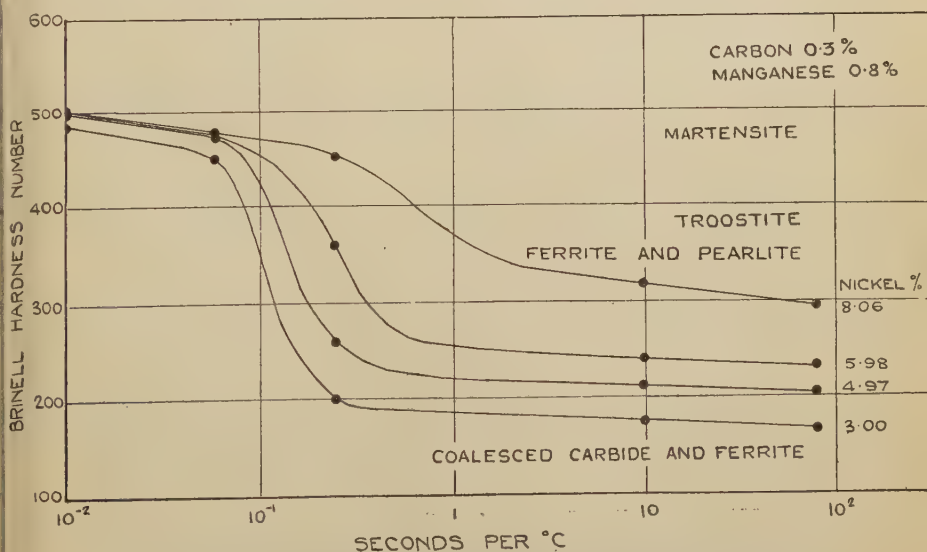


FIG. 6.—Hardness after Different Rates of Cooling. Effect of Nickel.

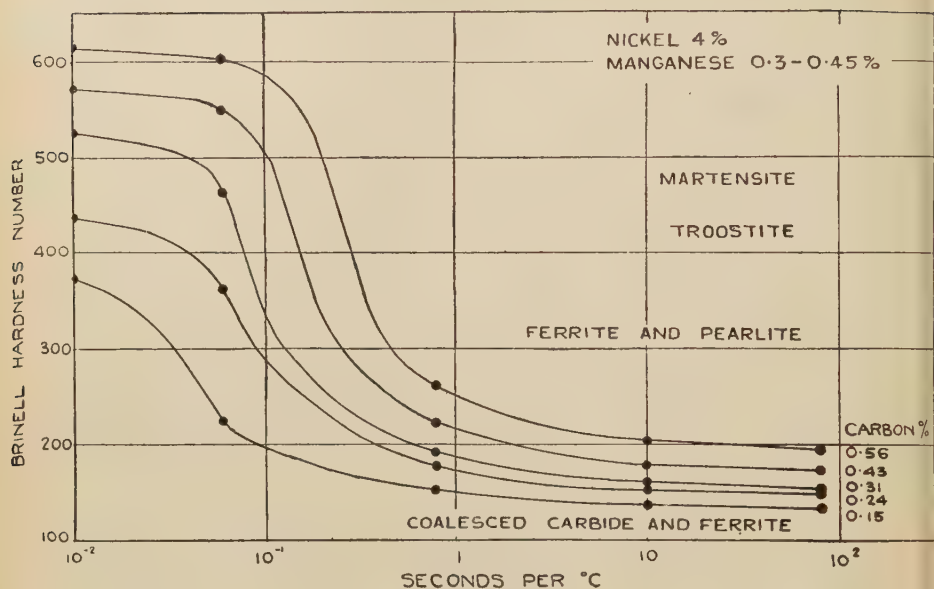


FIG. 7.—Hardness after Different Rates of Cooling. Effect of Carbon.

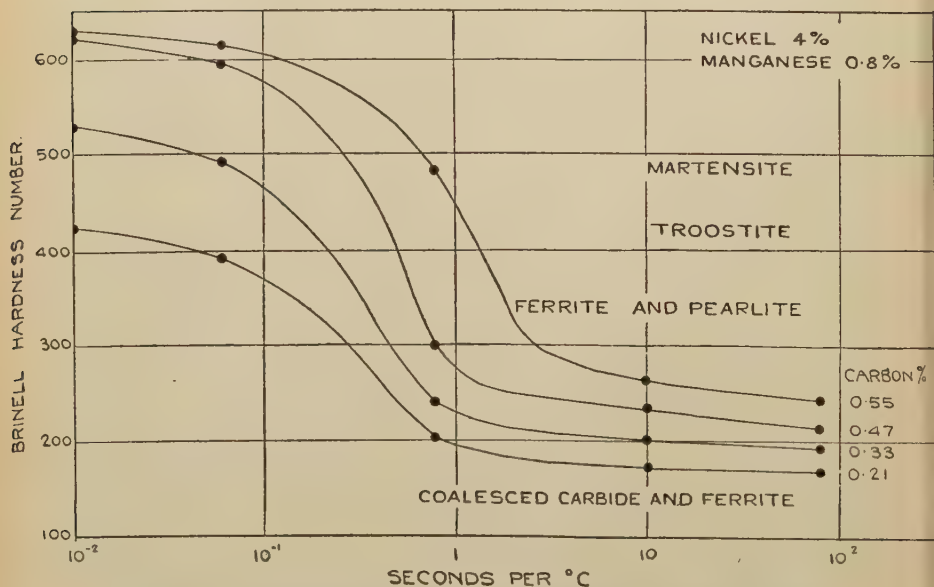


FIG. 8.—Hardness after Different Rates of Cooling. Effect of Carbon.

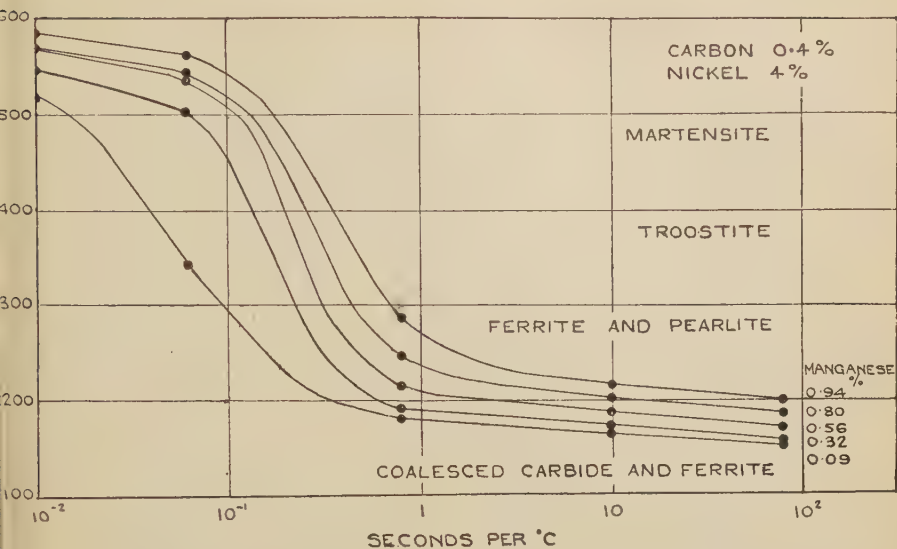


FIG. 9.—Hardness after Different Rates of Cooling. Effect of Manganese.

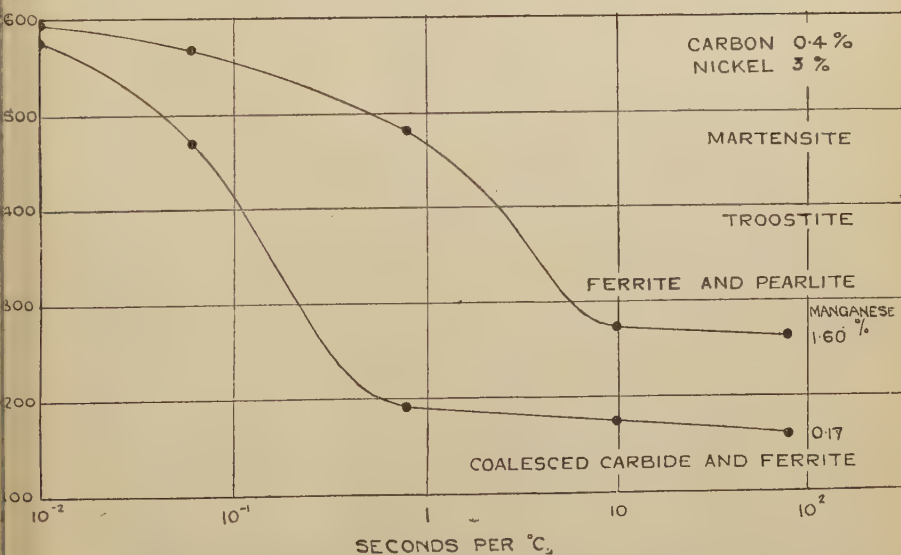


FIG. 10.—Hardness after Different Rates of Cooling. Effect of Manganese.
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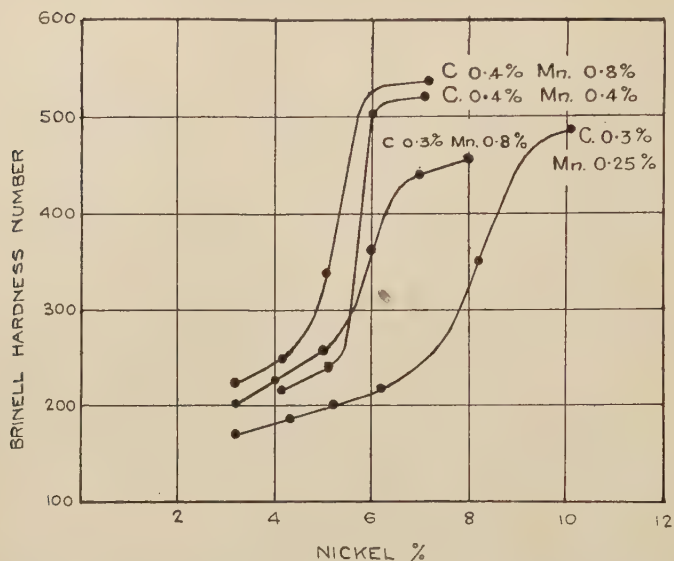


FIG. 11.—Hardness of Air-Cooled Specimens. Effect of Nickel. (Rate of cooling, 4° C. per sec. between 850° C. and 500° C.)

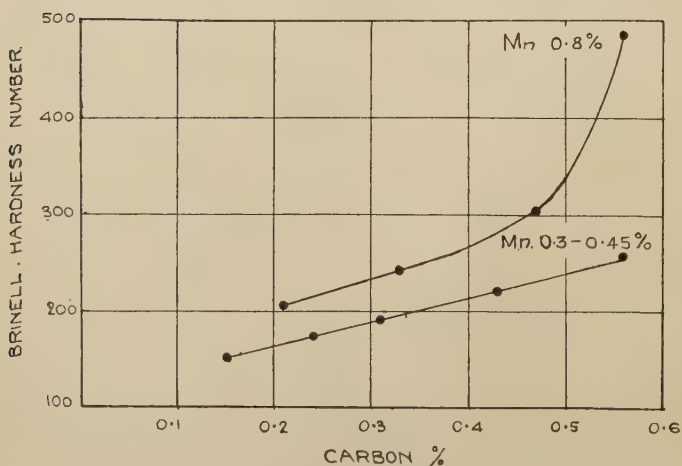


FIG. 12.—Hardness of Air-Cooled Specimens. Effect of Carbon. (Rate of cooling, 4° C. per sec. between 850° C. and 500° C.)

though the temperature at which the Ar points occur influences the degree of hardening on quenching.

Since the effect of manganese between 0.4 and 0.8 per cent. on the position of the Ac points is only very small, the temperatures of heat treatment of commercial nickel steels are not appreciably affected by the manganese content, though the behaviour of the steel in cooling is influenced by the amount of manganese present.

The addition of chromium up to 0.22 per cent. to a 4 per cent. nickel steel seems to have little effect on the Ac_3 , Ar_3 , and Ar_1 points, but the Ac_1 point is decidedly raised, the effect amounting to 7° C. when 0.22 per cent. of chromium is present.

EFFECT OF RATE OF COOLING ON HARDNESS.

Hardness tests and microscopical examination were made on small pieces ($1 \times \frac{1}{2} \times \frac{3}{8}$ in.) cooled from 850° C. at different rates through the critical range. The results of hardness tests are given in Table III., and typical results are illustrated in Figs. 5 to 10. The microstructure is also indicated on these diagrams.

TABLE III.—*Brinell Hardness Numbers of Steels Cooled at Different Rates.*

Steel No.	Carbon. %	Manganese. %	Nickel. %	Average Rate of Cooling between 850° C. and 500° C.				
				(Water) 100° C. per sec.	(Oil) 16° C. per sec.	(Air) 4° C. per sec.	(Furnace.)	
							1 ₁₀ ° C. per sec.	1 ₅₀ ° C. per sec.
1	0.30	0.26	3.21	506	273	172	153	147
2	0.29	0.25	4.32	504	385	186	162	153
3	0.30	0.28	5.22	519	490	201	176	163
4	0.30	0.28	6.22	520	491	217	186	175
5	0.28	0.26	8.24	502	496	352	208	195
6	0.31	0.25	10.12	520	497	488	322	320
7	0.28	0.84	3.00	486	463	201	176	165
8	0.31	0.86	4.00	506	471	228	200	186
9	0.31	0.79	4.97	506	477	260	214	204
10	0.29	0.80	5.98	502	480	361	240	230
11	0.26	0.80	6.99	482	470	440	270	255
12	0.28	0.81	8.06	500	479	455	320	295
13	0.37	0.42	4.13	553	513	219	191	169
14	0.38	0.45	5.13	572	524	240	198	184
15	0.41	0.44	6.07	590	548	502	212	207
16	0.40	0.45	7.16	584	545	520	228	220
17	0.39	0.43	8.06	579	540	527	269	244

TABLE III. (*continued*).

Steel No.	Carbon. %	Manganese. %	Nickel. %	Average Rate of Cooling between 850° C. and 500° C.				
				(Water) 100° C. per sec.	(Oil) 16° C. per sec.	(Air) 4° C. per sec.	(Furnace.)	
							10° C. per sec.	10° C. per sec.
18	0.38	0.87	3.19	555	520	225	198	185
19	0.38	0.81	4.17	560	533	248	206	197
20	0.40	0.87	5.08	572	548	338	234	227
21	0.40	0.87	7.20	575	558	538	365	318
22	0.15	0.27	4.35	377	226	153	137	133
23	0.24	0.35	4.08	439	364	176	154	148
24	0.31	0.36	4.10	524	463	190	159	153
25	0.43	0.40	4.28	570	550	220	177	171
26	0.56	0.45	4.26	614	601	259	204	192
27	0.21	0.81	4.05	422	394	206	174	170
28	0.33	0.80	4.12	531	493	241	204	193
29	0.47	0.81	4.17	615	589	303	238	214
30	0.55	0.84	4.15	629	618	486	265	246
31	0.40	0.09	3.81	520	341	180	166	153
32	0.38	0.13	4.00	541	438	179	166	154
33	0.39	0.32	3.76	547	504	191	175	158
34	0.38	0.43	3.97	569	534	202	177	160
35	0.41	0.56	3.94	571	534	215	189	173
36	0.41	0.80	3.95	571	543	249	204	188
37	0.41	0.94	4.02	585	561	288	215	201
38	0.42	0.17	3.09	574	470	191	175	156
39	0.39	0.60	2.98	547	495	192	175	156
40	0.34	0.83	3.00	522	501	205	182	169
41	0.43	1.60	2.96	598	567	481	272	264
43	0.37	0.42	4.13	553	513	219	191	169
42	0.40	0.45	4.12	566	538	236	209	179
43	0.39	0.44	Chromium	561	536	242	214	186
			0.15					
			4.13					
			Chromium					
			0.22					

In view of the fact that the transition from one type of structure to another is gradual, the boundaries must be regarded as only approximate. The effect of nickel, manganese, and carbon in increasing the maximum hardness of the steel and in maintaining the increased hardness at slow rates of cooling is shown in Figs. 11 and 12.

MECHANICAL PROPERTIES OF THE HEAT-TREATED STEELS.

Tests were made after a series of heat treatments, consisting of oil-hardening from 850° C. and tempering for 2 hours at 500° to 640° C., followed by cooling in air. The results of tensile, Brinell hardness, and notched-bar impact tests are given in Table IV., and are illustrated in Figs. 13 to 15.

All test-pieces were taken in the longitudinal direction. Extensions were measured by means of a Ewing extensometer, and the yield point was taken as the load giving a permanent extension of 0.2 per cent. (0.004 in. on 2 in.). The notched-bar impact tests were carried out in a 120 ft.-lb. Izod machine on 3-notch test-pieces of the B.E.S.A. standard form (45° V-notch with a root radius of 0.25 mm., and 2 mm. deep). In all cases the notches were on the side of the specimen which had originally been nearest the centre of the bar.

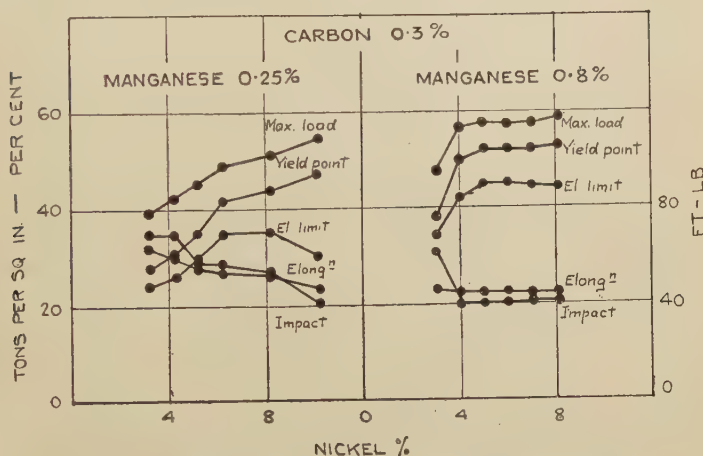


FIG. 13.—Mechanical Properties. Steels Oil-Hardened from 850° C. and Tempered at 550° C. Effect of Nickel.

In the following summary of the influence of composition on the mechanical properties, the properties considered are those of a steel bar having a cross-section $1\frac{3}{4} \times \frac{3}{4}$ in., oil-hardened from 850° C. and tempered at 500° to 640° C. On account of the influence of mass these conclusions would require some modification if applied to heat-treated bars of any other dimensions.

In nickel steels with low manganese contents and tempered at 500° to 550° C., marked improvement in properties occurs when the nickel content is raised to 6 per cent., but with a tempering temperature of 600° C. (which approaches the beginning of the Ac_1 range in steels of high nickel content) the improvement is not maintained. With higher manganese content (0.8 per cent.) no

TABLE IV.—*Mechanical Properties of Steels treated in Sections $1\frac{3}{4} \times \frac{3}{4}$ in. and 5 in. Long, Oil-Hardened from 850° C. and Tempered at Different Temperatures for 2 Hours, followed by Cooling in Air.*

Steel No.	Carbon. %	Manganese. %	Nickel. %	Tempering Temperature, ° C.	Elastic Limit. Tons per sq. in.	Yield Point. Tons per sq. in.	Maximum Load. Tons per sq. in.	Yield Ratio.	Elongation. %	Reduction of Area. %	Average Brinell Hardness Number.	Average Izod Impact Figure. Ft.-lb.
1	0.30	0.26	3.21	500	25	30.0	41.9	0.72	31	64	192	64
				550	24	27.7	39.3	0.71	32	65	181	70
				600	22	27.0	37.9	0.71	35	68	173	78
2	0.29	0.25	4.32	500	27	32.0	44.2	0.75	29	64	205	61
				550	26	30.5	42.0	0.73	30	65	195	71
				600	24	29.0	40.1	0.72	33	69	184	72
3	0.30	0.28	5.22	500	36	40.0	51.0	0.78	25	63	243	52
				550	30	34.9	45.1	0.77	28	64	212	58
				600	25	32.0	43.2	0.74	30	67	203	67
4	0.30	0.28	6.22	500	43	50.0	56.6	0.88	24	62	270	44
				550	35	42.0	48.6	0.86	27	64	233	58
				600	25	33.8	46.8	0.72	30	65	217	61
5	0.28	0.26	8.24	630	21	32.0	45.6	0.70	30	62	208	57
				500	44	53.6	57.0	0.94	21	57	277	34
				550	35	43.9	50.3	0.87	26	63	242	54
6	0.31	0.25	10.12	600	18	34.4	54.5	0.62	25	57	242	46
				550	30	47.0	54.5	0.86	23	50	260	41
				575	28	44.1	54.7	0.81	25	58	258	44
7	0.28	0.84	3.00	600	14	34.0	67.0	0.51	21	45	277	33
				550	34	38.0	47.8	0.80	23	66	231	61
				600	32	37.8	47.2	0.80	24	66	229	65
8	0.31	0.86	4.00	550	42	50.0	56.2	0.89	22	62	271	39
				600	41	46.5	52.4	0.89	23	65	252	47
				550	45	52.3	57.6	0.90	22	62	277	39
9	0.31	0.79	4.97	600	39	46.4	53.1	0.87	24	65	255	46
				550	45	52.0	57.3	0.90	22	62	277	40
				600	37	46.6	54.2	0.86	24	63	261	46
10	0.29	0.80	5.98	550	44	52.0	57.6	0.90	22	62	280	41
				600	32	45.6	55.5	0.82	24	62	264	46
				550	44	52.8	58.8	0.90	22	62	284	41
11	0.26	0.80	6.99	600	23	44.6	58.2	0.77	23	59	271	46
				550	40	44.9	53.7	0.84	21	54	260	42
				600	38	43.4	50.9	0.85	25	62	239	47
12	0.28	0.81	8.06	630	32	40.0	49.3	0.81	25	59	231	52
				550	45	50.9	56.3	0.90	22	59	270	38
				600	38	45.2	52.6	0.86	23	62	250	45
13	0.37	0.42	4.13	550	47	53.0	58.9	0.90	20	60	282	36
				600	37	45.8	55.9	0.82	22	59	264	42
				550	46	53.4	59.0	0.91	22	58	284	35
14	0.38	0.45	5.13	600	31	43.8	57.4	0.76	21	56	267	37
				550	45	54.2	59.5	0.91	21	58	287	35
				600	27	43.0	61.2	0.70	21	55	276	36
15	0.39	0.43	8.06	550	43	50.0	57.7	0.87	22	61	270	40
				600	41	45.6	52.6	0.87	22	64	248	49
				550	46	52.6	59.2	0.89	20	61	285	34
16	0.38	0.87	3.19	600	41	47.0	53.9	0.87	22	63	260	43
				550	49	56.0	61.1	0.92	20	61	290	34
				600	37	47.0	55.5	0.85	22	63	263	43
17	0.40	0.87	7.20	550	45	57.0	64.1	0.89	20	52	303	29
				600	30	44.0	65.4	0.67	20	52	284	36
				550	23	27.8	35.4	0.79	35	75	166	107
18	0.15	0.27	4.35	500	28	30.8	41.0	0.75	31	66	191	69
				550	27	30.4	40.0	0.76	31	68	186	75
				600	33	34.9	46.8	0.74	24	59	217	49
19	0.24	0.35	4.08	550	29	33.0	44.4	0.74	28	64	204	59
				500	33	34.9	46.8	0.74	24	59	217	49
				550	38	42.2	51.9	0.81	24	57	246	39
20	0.31	0.36	4.10	600	32	35.3	47.8	0.74	26	59	219	46
				550	24	31.0	45.4	0.68	28	62	216	52
				600	44	48.9	57.2	0.86	21	52	269	29
21	0.43	0.40	4.28	600	37	41.4	51.2	0.81	24	55	238	36
				550	44	48.9	57.2	0.86	21	52	269	29
				630	27	35.9	49.8	0.72	25	56	231	37

TABLE IV. (continued).

Steel No.	Carbon. %	Manganese. %	Nickel. %	Tempering Temperature. ° C.	Elastic Limit. Tons per sq. in.	Yield Point. Tons per sq. in.	Maximum Load. Tons per sq. in.	Yield Ratio.	Elongation. %	Reduction of Area. %	Average Brinell Hardness Number.	Average Izod Impact Figure. Ft.-lb.
27	0.21	0.81	4.05	550	37	42.6	49.3	0.86	24	68	241	59
				600	35	40.7	46.8	0.87	26	69	225	72
				630	36	40.2	46.6	0.86	25	70	225	80
				640	27	36.0	47.5	0.76	25	66	225	79
28	0.33	0.80	4.12	550	44	51.0	57.3	0.89	21	64	272	39
				600	40	46.4	52.4	0.89	22	65	253	50
				630	37	45.4	52.4	0.87	23	66	249	50
				640	26	38.8	51.8	0.75	24	61	245	52
29	0.47	0.81	4.17	550	46	54.8	62.4	0.88	20	55	296	35
				600	41	48.4	56.0	0.86	22	59	264	45
				630	37	45.0	54.4	0.83	22	57	258	50
				640	28	39.0	55.5	0.70	21	52	259	50
30	0.55	0.84	4.15	550	45	56.2	64.0	0.88	19	51	304	29
				600	41	49.4	57.8	0.85	22	52	272	40
				630	36	44.4	56.5	0.79	22	56	265	36
				640	27	39.4	57.9	0.68	21	52	266	36
31	0.40	0.09	3.81	500	28	32.6	46.6	0.70	23	56	220	45
				550	28	31.6	44.1	0.72	26	57	206	48
32	0.38	0.13	4.00	500	27	31.8	45.8	0.69	25	57	218	39
				550	27	31.3	43.9	0.71	27	58	203	56
33	0.39	0.32	3.76	500	29	33.8	48.8	0.69	25	55	229	37
				550	30	32.9	46.4	0.71	25	57	217	44
34	0.38	0.43	3.97	600	26	30.0	43.8	0.68	25	56	204	44
				500	33	36.8	52.2	0.70	24	55	243	37
				550	31	34.9	49.2	0.71	24	57	229	51
				600	29	34.1	46.6	0.73	24	58	218	54
35	0.41	0.56	3.94	630	29	32.9	45.0	0.73	29	62	208	55
				500	43	49.4	58.4	0.85	20	51	280	42
				550	38	43.3	53.2	0.83	22	57	255	53
				600	31	36.9	47.5	0.78	23	58	226	61
36	0.41	0.80	3.95	630	31	36.2	46.2	0.78	27	62	217	66
				640	26	29.6	44.4	0.67	25	58	207	62
				500	47	53.6	62.1	0.86	20	54	297	37
				550	44	48.7	56.1	0.87	22	58	268	44
37	0.41	0.94	4.02	600	38	42.8	50.4	0.85	24	63	240	55
				630	33	38.0	47.6	0.80	28	63	224	61
				640	24	34.0	48.1	0.71	26	59	222	63
				500	49	55.0	63.4	0.87	20	52	302	37
38	0.42	0.17	3.09	550	46	49.6	57.1	0.87	22	55	273	46
				600	39	43.9	51.2	0.86	24	59	244	56
				630	34	38.5	48.4	0.80	27	62	227	64
				640	23	33.4	49.0	0.68	25	57	225	67
39	0.39	0.60	2.98	500	32	35.0	50.1	0.70	25	57	235	38
				550	31	34.4	47.5	0.72	26	57	224	50
				600	28	32.0	44.9	0.71	28	62	205	50
				630	32	35.8	49.2	0.73	24	59	230	47
40	0.34	0.83	3.00	500	30	34.9	46.9	0.74	27	64	217	49
				550	30	33.5	45.2	0.74	28	65	208	58
				600	27	42.2	54.1	0.78	21	59	263	44
				550	35	39.2	50.4	0.78	25	63	242	50
41	0.43	1.60	2.96	600	31	34.8	46.3	0.75	27	66	221	56
				630	29	32.9	44.5	0.74	26	68	217	61
				500	57	62.0	69.8	0.89	17	45	333	4
				550	52	56.9	64.1	0.89	19	50	302	10
13	0.37	0.42	4.13	600	43	48.6	57.0	0.85	22	56	267	27
				630	40	44.0	53.3	0.83	23	57	262	41
				550	40	44.9	53.7	0.84	21	54	260	42
				600	38	43.4	50.9	0.85	25	62	239	47
42	0.40	0.45	4.12 Chro- mium	630	32	40.0	49.3	0.81	25	59	231	52
				550	45	53.0	59.6	0.89	21	55	276	34
				600	42	48.0	54.8	0.88	22	59	258	42
				630	35	42.8	52.0	0.82	24	62	245	46
43	0.39	0.44	4.13 Chro- mium	550	45	53.6	60.6	0.89	20	55	284	31
				600	41	48.4	55.3	0.88	22	61	263	43
				630	35	42.9	52.6	0.82	24	62	247	46
				0.22								

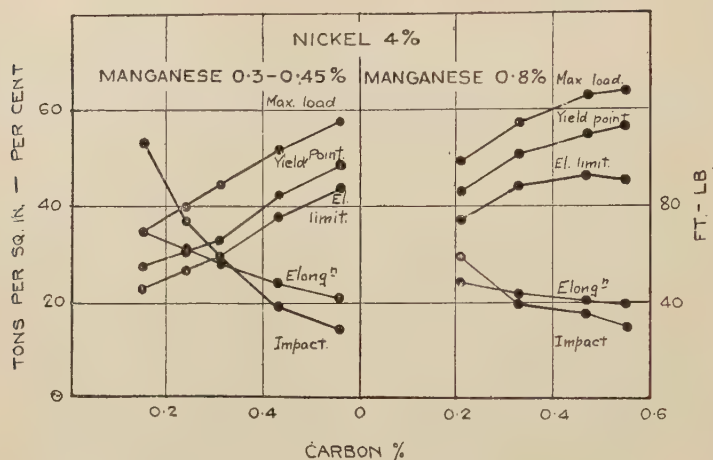


FIG. 14.—Mechanical Properties. Steel Oil-Hardened from 850° C. and Tempered at 550° C. Effect of Carbon.

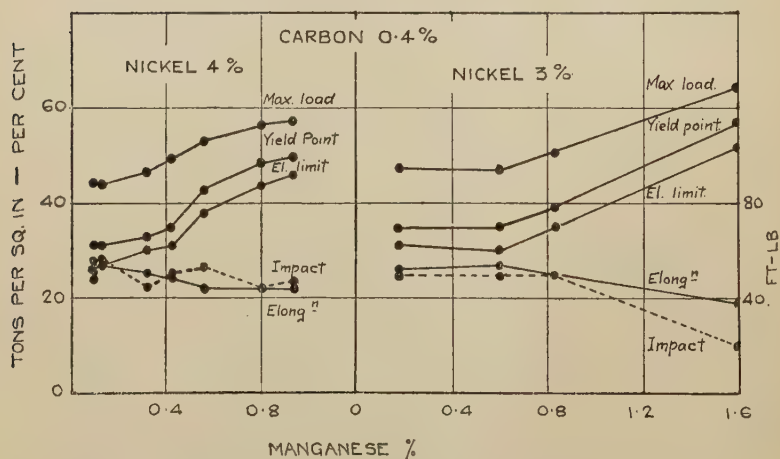


FIG. 15.—Mechanical Properties. Steels Oil-Hardened from 850° C. and Tempered at 550° C. Effect of Manganese.

appreciable advantage is gained by exceeding 4.5 per cent. of nickel, while the harmful effect of tempering at 600° C. becomes evident with 5 per cent. of nickel.

The influence of an increase in carbon content on the properties of nickel steel is similar to its effect on those of a plain carbon steel, and in both cases the magnitude of the effect is reduced by the presence of high manganese.

The effect of progressively increasing the manganese content has been studied more particularly in the 3 and 4 per cent. nickel steels. In 4 per cent. nickel steels the influence of manganese begins to be pronounced above 0.4 per cent. The improvement in elastic properties and yield point without loss of ductility is very pronounced when the manganese is raised from 0.4 to 0.7 per cent. For steels containing 3 per cent. of nickel the marked improvement in properties becomes evident at a higher percentage of manganese. The manganese content at which these changes in tensile properties occur is dependent on the cross-section of the bar subjected to treatment. The influence of mass in this connection is considered later.

LIMITS OF TEMPERING TEMPERATURE.

The Lower Limit.—With the increasing demand for higher tensile properties in modern steel structures there is a tendency to employ steels which, to meet the requirements of the specifications, require tempering at a low temperature. The tendency to use a low tempering temperature also occurs when incomplete hardening has been obtained by quenching. It is important that the tempering temperature of steels employed for constructional purposes should not be too low, otherwise internal stresses set up in quenching are not removed, and the elastic limit of the treated steel is low. The effect of tempering at low temperatures is shown by the results obtained on two nickel steels (Nos. 33 and 34) of such composition as to give only partial hardening when sections $1\frac{3}{4} \times \frac{3}{4}$ in. are quenched in oil. Tests are given in Table V. and illustrated in Fig. 16 for the steels in the oil-quenched condition, and also after tempering at temperatures from 200° to 630° C. From these results it will be seen that the hardness and tensile strength fall steadily with an increase of tempering temperature,

but the maximum elastic limit and yield ratio are only attained when a tempering temperature of at least 500° C. is employed. It is therefore considered inadvisable to make use of such steels as require tempering below 500° C. for structural purposes. Also, since a high manganese content increases the susceptibility of nickel steels to temper-brittleness,⁽⁶⁾ caution should be exercised in tempering a nickel steel with over 0.7 per cent. of manganese within the embrittling range (up to 560° C.).

TABLE V.—*Effect of Tempering Temperature on the Mechanical Properties.*

Sections ($5 \times 1\frac{3}{4} \times \frac{3}{4}$ in.) oil-hardened from 850° C., tempered for 2 hours, followed by cooling in air.

Steel 33—Carbon 0.39, manganese 0.32, nickel 3.76 per cent.

„ 34 „ 0.38, „ 0.43, „ 3.97 „

Steel.	Temper- ing Tem- per- ature. ° C.	Elastic Limit. Tons per sq. in.	Yield Point. Tons per sq. in.	Maxi- mum Load. Tons per sq. in.	Yield Ratio.	Elong- ation. %	Reduc- tion of Area. %	Average Brinell Hard- ness Number.	Average Izod Impact Figure. Ft.-lb.
33	...	13	33.8	55.6	0.61	14	37	256	21
	200	19	34.0	54.7	0.61	18	42	244	19
	300	24	33.8	52.8	0.64	20	47	237	25
	400	25	34.6	52.8	0.66	20	50	235	30
	450	28	34.9	51.5	0.68	21	52	232	33
	500	29	33.8	48.8	0.69	25	55	229	37
	550	30	32.9	46.4	0.71	25	57	217	44
	600	26	30.0	43.8	0.68	25	56	204	44
34	...	12	35.6	58.6	0.52	11	28	279	16
	200	19	37.6	58.2	0.65	13	39	271	21
	300	25	36.0	56.0	0.64	17	41	259	27
	400	26	35.7	54.0	0.66	19	46	250	29
	450	32	37.6	53.7	0.70	21	46	250	32
	500	33	36.8	52.2	0.70	24	55	243	37
	550	31	34.9	49.2	0.71	24	57	229	51
	600	29	34.1	46.6	0.73	24	58	218	54
	630	29	32.9	45.0	0.73	29	62	208	55

The Upper Limit.—Under the conditions employed in tempering hardened steel of heavy section (that is, slowly heating, and holding at a tempering temperature for a fairly prolonged time), the Ac_1 range is found to start at a considerably lower temperature than that given by ordinary thermal curves.⁽⁶⁾

In steels cooled rapidly after tempering the hardness is not progressively lowered with a rise of tempering temperature to Ac_1 . The increase in hardness which may occur on air-cooling

after holding for some time at a temperature considerably below A_{c1} as ordinarily determined is accompanied by a marked fall in the elastic limit, yield ratio, elongation, and impact figure. If slow cooling is adopted after the same tempering treatment the hardening effect is not produced, but the effect on the elastic limit is similar, and it is accompanied by a fall in the yield point. In

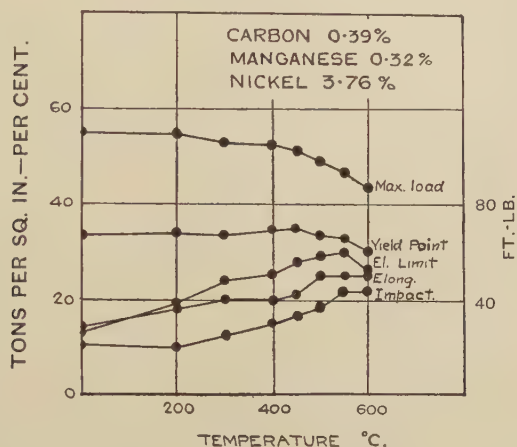


FIG. 16.—Mechanical Properties of Steel 30 ($5 \times 1\frac{3}{4} \times \frac{3}{4}$ in.), Oil-Hardened from 850°C . Effect of Tempering for 2 Hours at Various Temperatures.

both cases, therefore, there is considerable danger that the steel thus heat-treated may be rendered unserviceable.

The results given in Table VI. show the effect of increasing tempering temperatures on the mechanical properties of a selection of the steels, and illustrate the deterioration in properties produced by tempering at the higher temperatures employed.

The safe upper limit of tempering temperature can also be determined by heating the steel at different temperatures, quenching in water, and observing the temperature on quenching from which the steel begins to show evidence of hardening.

Small specimens ($\frac{3}{8} \times \frac{1}{2}$ in. and 1 in. long) in the hardened and tempered condition were reheated for 2 hours at various temperatures below the critical range and quenched in water.

TABLE VI.—*Effect of High Tempering Temperatures on the Mechanical Properties of Sections Oil-Hardened from 850° C. and Tempered for 2 Hours, followed by Cooling in Air.*

(Tests on these Steels tempered at Lower Temperatures are given in Table IV.)

Steel No.	Carbon, %.	Manganese, %.	Nickel, %.	Tempering Temperature, °C.	Elastic Limit, Tons per sq. in.	Yield Point, Tons per sq. in.	Maximum Load, Tons per sq. in.	Yield Ratio.	Elongation, %.	Reduction of Area, %.	Average Brinell Hardness Number.	Average Izod Impact Figure, Ft.-lb.
1	0.30	0.26	3.21	630	19	26.0	36.7	0.71	35	70	166	79
				650	18	25.8	36.5	0.71	36	70	165	80
				660	18	25.6	36.2	0.71	36	70	162	79
				670	17	25.0	36.0	0.69	35	68	160	78
2	0.29	0.25	4.32	630	22	27.9	39.2	0.71	34	70	179	77
				640	19	27.0	38.7	0.70	34	70	174	80
				650	18	26.4	38.2	0.69	34	70	172	80
				660	17	25.3	37.3	0.68	33	70	167	80
3	0.30	0.28	5.22	600	25	32.0	43.2	0.74	30	67	203	67
				620	21	28.0	42.8	0.65	28	64	195	67
				630	20	26.7	42.2	0.63	28	64	191	66
				640	18	26.0	42.1	0.62	29	64	189	65
				650	17	25.6	41.4	0.62	29	63	186	64
4	0.30	0.28	6.22	550	35	42.0	48.6	0.86	27	64	233	58
				600	25	33.8	46.8	0.72	30	65	217	61
				620	23	32.9	46.1	0.70	30	63	212	59
				630	21	32.0	45.6	0.70	30	62	208	57
				640	18	30.6	46.0	0.67	28	61	205	57
28	0.33	0.80	4.12	630	37	45.4	52.4	0.87	23	66	249	50
				640	26	38.8	51.8	0.75	24	61	245	52
				650	20	37.6	54.6	0.69	22	54	254	44
29	0.47	0.81	4.17	630	37	45.0	54.4	0.83	22	57	258	50
				640	28	39.0	55.5	0.70	21	52	259	50
				650	19	37.8	58.2	0.65	20	50	264	37

Results of hardness tests are given in Table VII. Comparison with the tensile tests (Table VI.) shows that the temperature at which the steel begins to show hardening is coincident with the temperature of tempering at which the undesirable qualities begin to be developed. The beginning of the Ac_1 range is about 60° C. below the maximum of the point shown in thermal curves. It is depressed slightly by an increase in manganese content (steels 2 and 28) and by an increase in carbon content (steels 28 and 29).

TABLE VII.—*Effect of High Tempering Temperatures. Determination of the Beginning of A_{c1} by Measurement of Brinell Hardness after Soaking for 2 Hours at the Temperature indicated and Quenching in Water.*

Steel No. :	1.	2.	3.	4.	28.	29.
Carbon, % . . .	0.30	0.29	0.30	0.30	0.33	0.47
Nickel, % . . .	3.21	4.32	5.22	6.22	4.12	4.17
Manganese, % . . .	0.26	0.25	0.28	0.28	0.80	0.81
<i>Brinell Hardness Number.</i>						
Tempered at 550° C. . .	190	204	240	248	284	308
Reheated to :						
600° C. . . . .	...	...	219	227	263	274
608° C. . . . .	...	...	211	<u>219</u>	256	266
618° C. . . . .	...	190	<u>209</u>	220	<u>252</u>	<u>259</u>
630° C.	176	184	215	240	<u>250</u>	259
637° C.	174	<u>183</u>	227	259	<u>250</u>	269
648° C.	<u>173</u>	207	279	357	288	307
662° C.	<u>175</u>	250	...	...	...	...
<i>Temperature. ° C.</i>						
Beginning of A_{c1} derived from hardness tests . .	648	640	624	613	633	624
A_{c1} (max.) on thermal curve	707	698	688	678	688	688

MASS EFFECT.

In the heat treatment of steel the "mass effect," or influence of the size of the piece on the rate of cooling in hardening, and hence on the properties obtained, is a matter of great importance. Improved properties can be secured in all steels by hardening and tempering. Satisfactory hardening can only be secured when the steel is first brought into a condition in which complete solution of the ferrite and carbide has been obtained by heating it above the upper limit of the critical range, and is then cooled through the critical range at a rate which is sufficiently rapid to prevent the separation of ferrite and to retain a homogeneous hardened structure. In this condition the steel can be tempered to give uniform sorbite with no free ferrite, and this type of micro-structure is associated with the best properties for constructional

purposes. Small sections of medium-carbon steel can be hardened and tempered to give such a structure, but no carbon steel can be satisfactorily hardened in sections of any considerable size, because it is impossible to obtain a sufficiently rapid rate of cooling. Nickel steel was the first alloy steel used to replace carbon steel with a view to obtaining more efficient hardening.

The pronounced effect of the manganese content in nickel steels on the behaviour of the steel treated in the mass is not generally realised. Some investigation has been made of the influence of manganese in reducing the mass effect in nickel steel. The presence of manganese has a pronounced effect in preventing the separation of ferrite and pearlite on cooling. A 4 per cent. nickel steel with only 0.2 per cent. of manganese will not harden efficiently when quenched in oil, even in very small sections, but there is, at about 0.5 per cent., a critical percentage of manganese at which the efficiency of the hardening with the same rate of cooling is greatly increased. The amount of manganese required to induce efficient hardening varies with the section treated and with the carbon and nickel contents of the steel. The results of hardness tests on the various steels in the hardened condition are given in Table VIII. (pp. 322-323), and are illustrated in Figs. 17 to 20.

The most useful way in which the practical application of these results may be expressed is to consider the limits of composition which are necessary to secure efficient hardening in bars of different sections. The transition from efficient to inefficient hardening is gradual, and steels outside these limits of composition will show marked improvement in properties on treatment though they may not be capable of deriving the maximum benefit from the treatment.

Thus, inspection of Fig. 17 indicates that with carbon 0.3 per cent. and manganese only 0.25 per cent. it is useless to expect to derive any material advantage by oil-hardening a $1\frac{1}{2}$ -in. bar containing less than 7.5 per cent. of nickel, while a similar steel with 0.8 per cent. of manganese only requires 3.5 per cent. of nickel to ensure the full advantage of oil-hardening in a bar $1\frac{1}{2}$ in. square in section, or 5 per cent. of nickel for a 2-in. square bar. Increase of carbon content from 0.3 to 0.4 per cent. has the effect of lowering very slightly the above limits for nickel content.

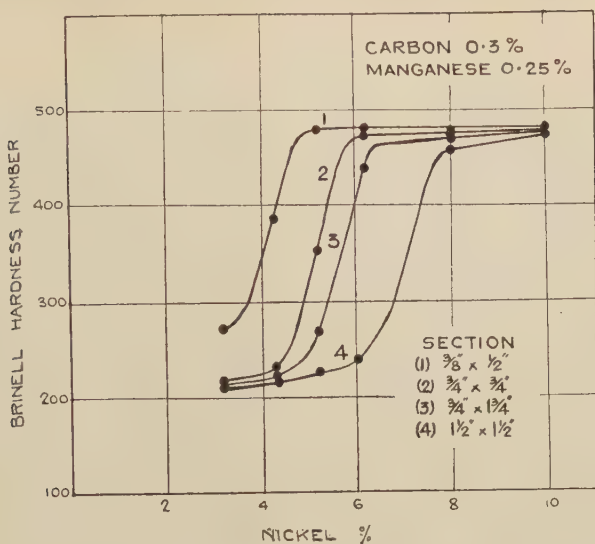


FIG. 17.—Hardness of Different Sections quenched in Oil. Effect of Nickel.

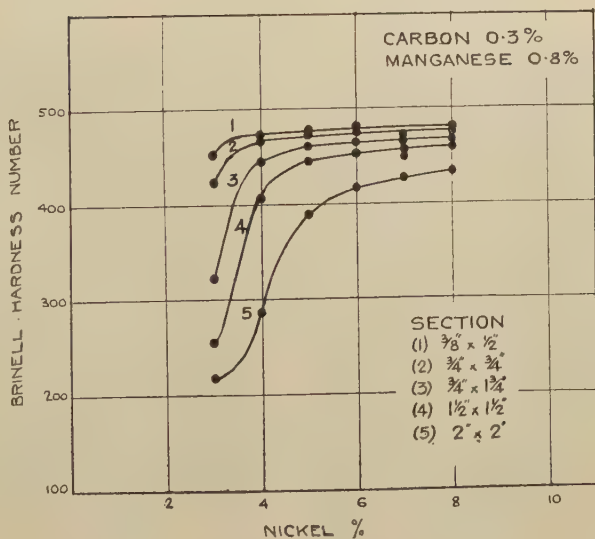


FIG. 18.—Hardness of Different Sections quenched in Oil. Effect of Nickel.

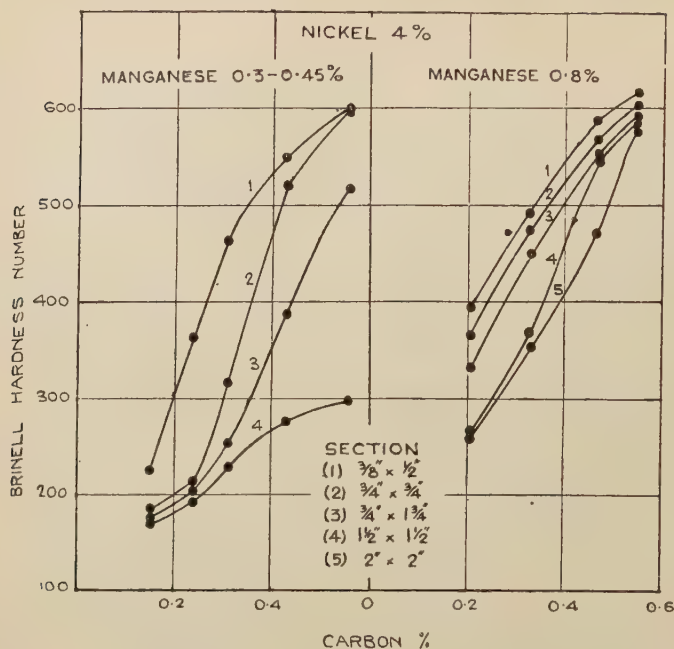


FIG. 19.—Hardness of Different Sections quenched in Oil.
Effect of Carbon.

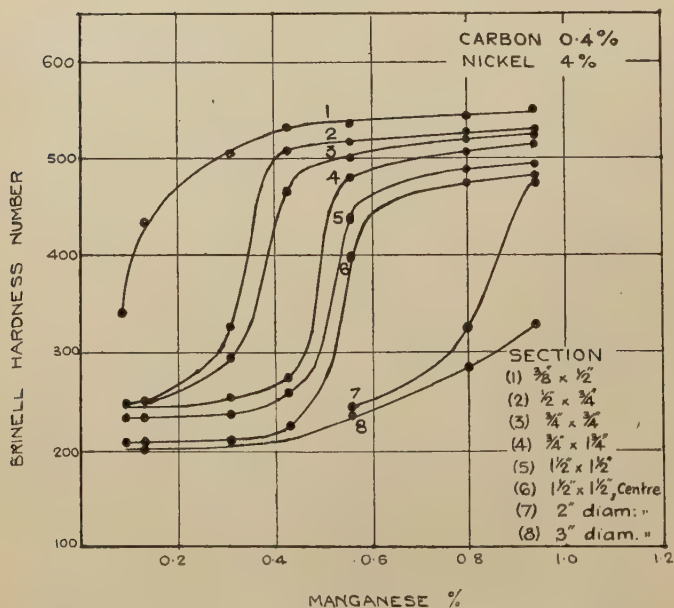


FIG. 20.—Hardness of Different Sections quenched in Oil.
Effect of Manganese.

Nickel steels oil-hardened from 850° C., and tempered at 550° C.

Carbon 0·4 per cent. Nickel 4 per cent.

Magnification 250 diam.



FIG. 21.—Steel 34. Manganese 0·43 per cent. Treated in $\frac{3}{8} \times \frac{1}{2}$ in. section.



FIG. 22.—Steel 34. Manganese 0·43 per cent. Treated in $\frac{3}{4} \times \frac{3}{4}$ in. section.



FIG. 23.—Steel 34. Manganese 0·43 per cent. Treated in $1\frac{1}{2} \times 1\frac{1}{2}$ in. section.



FIG. 24.—Steel 19. Manganese 0·81 per cent. Treated in $1\frac{1}{2} \times 1\frac{1}{2}$ in. section

Nickel steels oil-hardened from 850° C., and tempered at 550° C., in sections $\frac{3}{4} \times 1\frac{3}{4}$ in.
Carbon 0.3 per cent. Manganese 0.25 per cent.
Magnification 500 diam.



FIG. 25.—Steel 1. Nickel 3.21 per cent.



FIG. 26.—Steel 3. Nickel 5.22 per cent.



FIG. 27.—Steel 4. Nickel 6.22 per cent.



FIG. 28.—Steel 5. Nickel 8.24 per cent.

Thus a certain minimum manganese content is essential in nickel steels. Without this minimum amount of manganese, an increase in carbon content is of no use in counteracting mass effect. It will always ensure a higher tensile strength in sections of any given size, but it has no other advantage, and may make it difficult to obtain a satisfactory elongation and impact figure.

The effect of chromium in such quantities as occur in a nominal nickel steel (that is, up to 0.2 per cent.) is more powerful in counteracting mass effect than an equal additional quantity of manganese.

MECHANICAL PROPERTIES OF STEELS TREATED IN VARIOUS SECTIONS.

Tensile, Brinell hardness, and notched-bar impact tests were carried out on the 5-in. specimens used for hardness tests in the hardened condition, after tempering for 2 hours at 550° C., and cooling in air. These results are given in Table IX. (pp. 324-327). The tensile test-pieces were taken from the centre of the bars.

The conclusions as regards limits of composition necessary to secure the full advantage of oil-hardening are supported by the results of these tensile tests, which show, after identical treatment, a marked improvement in the elastic limit, yield ratio, and percentage reduction of area without appreciable deterioration in the elongation and impact figures at the compositions indicated in the foregoing paragraphs.

When a steel is not efficiently hardened and consequently has a low initial Brinell hardness, accompanied by the separation of ferrite, the steel, after tempering, is excessively soft, and gives a low elastic limit, yield point, and maximum load.

Steel which has been efficiently hardened and subsequently tempered gives the best combination of elastic strength and ductility, including the notched-bar impact figure. The impact figure of steel in which ferrite has separated during oil-quenching is, in general, lower, though extreme softness, such as is produced when practically no hardening has taken place, may compensate for this effect and give rise to a higher impact figure.

The considerable differences in hardness after oil-hardening of sections of different sizes are greatly reduced by subsequent

TABLE VIII.—*Effect of Mass. Brinell Hardness Tests on Specimens of Various Cross-Sections, Oil-Hardened from 850° C. (all Brinell Tests made on the Surface of the Specimens except where Otherwise Stated).*

(a) *Influence of Nickel in Steel containing Carbon 0.3, Manganese 0.25 per cent.*

Steel No.	Nickel. %	Sections—			
		$\frac{3}{8} \times \frac{1}{2}$ in.	$\frac{1}{2} \times \frac{3}{4}$ in.	$\frac{3}{4} \times 1\frac{1}{2}$ in.	$1\frac{1}{2} \times 1\frac{1}{2}$ in.
1	3.21	270	216	208	210
2	4.32	385	229	224	217
3	5.22	480	351	266	226
4	6.22	481	474	439	237
5	8.24	479	476	469	460
6	10.12	480	480	478	473

(b) *Influence of Nickel in Steel containing Carbon 0.3, Manganese 0.8 per cent.*

Steel No.	Nickel. %	Sections—				
		$\frac{3}{8} \times \frac{1}{2}$ in.	$\frac{1}{2} \times \frac{3}{4}$ in.	$\frac{3}{4} \times 1\frac{1}{2}$ in.	$1\frac{1}{2} \times 1\frac{1}{2}$ in.	2×2 in.
7	3.00	453	423	321	256	218
8	4.00	471	468	446	409	287
9	4.97	477	472	461	445	388
10	5.98	480	476	466	453	417
11	6.99	470	465	457	450	429
12	8.06	479	475	468	460	433

(c) *Influence of Nickel in Steel containing Carbon 0.4, Manganese 0.4 per cent.*

Steel No.	Nickel. %	Sections—				
		$\frac{3}{8} \times \frac{1}{2}$ in.	$\frac{1}{2} \times \frac{3}{4}$ in.	$\frac{3}{4} \times 1\frac{1}{2}$ in.	$1\frac{1}{2} \times 1\frac{1}{2}$ in.	2×2 in.
13	4.13	513	494	385	276	236
14	5.13	524	516	488	409	326
15	6.07	548	541	527	518	471
16	7.16	545	542	528	525	501
17	8.06	540	539	529	526	502

(d) *Influence of Nickel in Steel containing Carbon 0.4, Manganese 0.8 per cent.*

Steel No.	Nickel. %	Sections—				
		$\frac{3}{8} \times \frac{1}{2}$ in.	$\frac{1}{2} \times \frac{3}{4}$ in.	$\frac{3}{4} \times 1\frac{1}{2}$ in.	$1\frac{1}{2} \times 1\frac{1}{2}$ in.	2×2 in.
18	3.19	520	508	436	270	240
19	4.17	533	526	502	458	350
20	5.08	548	539	517	512	476
21	7.20	558	544	528	526	517

TABLE VIII. (continued).

(e) Influence of Carbon in Steel containing Manganese 0·3 to 0·45, Nickel 4 per cent.

Steel No.	Carbon. %	Sections—				
		$\frac{3}{8} \times \frac{1}{2}$ in.	$\frac{1}{2} \times \frac{3}{4}$ in.	$\frac{3}{4} \times 1\frac{1}{2}$ in.	$1\frac{1}{2} \times 1\frac{1}{2}$ in.	$1\frac{1}{2} \times 1\frac{1}{2}$ in.
22	0·15	226	185	185	177	171
23	0·24	364	215	214	207	193
24	0·31	463	317	274	254	230
25	0·43	550	520	490	388	274
26	0·56	601	599	589	518	299

(f) Influence of Carbon in Steel containing Nickel 4, Manganese 0·8 per cent.

Steel No.	Carbon. %	Sections—					
		$\frac{3}{8} \times \frac{1}{2}$ in.	$\frac{1}{2} \times \frac{3}{4}$ in.	$\frac{3}{4} \times 1\frac{1}{2}$ in.	$1\frac{1}{2} \times 1\frac{1}{2}$ in.	2 × 2 in.	
						Surface.	Centre.
27	0·21	394	366	330	264	259	...
28	0·33	493	478	450	367	352	...
29	0·47	589	568	552	546	470	388
30	0·55	618	602	592	589	587	...

(g) Influence of Manganese in Steel containing Carbon 0·4, Nickel 4 per cent.

Steel No.	Manganese. %	Sections—							
		$\frac{3}{8} \times \frac{1}{2}$ in.	$\frac{1}{2} \times \frac{3}{4}$ in.	$\frac{3}{4} \times \frac{3}{4}$ in.	$\frac{3}{4} \times 1\frac{1}{2}$ in.	1½ × 1½ in.		Cylinder.	
						Surface.	Centre.	2-in. diam. Centre.	3-in. diam. Centre.
31	0·09	341	249	248	245	231	205	...	...
32	0·13	438	252	252	242	234	210	...	200
33	0·32	504	329	294	255	234	209	...	...
34	0·43	534	509	465	274	260	222	...	...
35	0·56	534	516	499	480	437	400	242	238
36	0·80	543	527	522	507	488	474	325	284
37	0·94	561	530	524	519	490	483	475	329

(h) Influence of Manganese in Steel containing Carbon 0·4, Nickel 3 per cent.

Steel No.	Manganese. %	Sections—			
		$\frac{3}{8} \times \frac{1}{2}$ in.	$\frac{1}{2} \times \frac{3}{4}$ in.	$\frac{3}{4} \times \frac{3}{4}$ in.	$\frac{3}{4} \times 1\frac{1}{2}$ in.
38	0·17	470	291	265	256
39	0·60	495	452	297	258
40	0·83	501	482	443	391
41	1·60	568	560	557	552

(i) Influence of Chromium in Steel containing Carbon 0·4, Manganese 0·4, Nickel 4 per cent.

Steel No.	Chromium. %	Sections—				
		$\frac{3}{8} \times \frac{1}{2}$ in.	$\frac{1}{2} \times \frac{3}{4}$ in.	$\frac{3}{4} \times 1\frac{1}{2}$ in.	$1\frac{1}{2} \times 1\frac{1}{2}$ in.	2 × 2 in.
13	Nil	513	494	385	276	236
42	0·15	538	523	483	325	273
43	0·22	536	520	480	401	302

tempering, and may be eliminated to a large extent by tempering at different temperatures, but the difference in the initial condition of the hardened steel will still be reflected in differences in the elastic limit, yield ratio, and impact figures.

TABLE IX.—*Mechanical Properties of Steels treated in Different Sections Oil-Hardened from 850° C. and tempered for 2 Hours at 550° C., followed by Cooling in Air.*

INFLUENCE OF NICKEL.

Steel No.	Nickel %	Cross-Section. In.	Elastic Limit. Tons per sq. in.	Yield Point. Tons per sq. in.	Maximum Load. Tons per sq. in.	Yield Ratio.	Elongation. %	Reduction of Area. %	Average Brinell Hardness Number.	Average Izod Impact Figure. Ft.-lb.
(a) Steels containing Carbon 0.3, Manganese 0.25 per cent.										
1	3.21	$\frac{3}{4} \times \frac{3}{4}$	25	29.2	40.4	0.72	30	68	183	71
		$\frac{1}{2} \times \frac{1}{2}$	24	27.7	39.3	0.71	32	65	181	70
		$1\frac{1}{2} \times 1\frac{1}{2}$	21	27.6	39.4	0.70	30	65	182	69
2	4.32	$\frac{3}{4} \times \frac{3}{4}$	27	32.0	42.2	0.76	29	68	194	75
		$\frac{1}{2} \times \frac{1}{2}$	26	30.5	42.0	0.73	30	65	195	71
		$1\frac{1}{2} \times 1\frac{1}{2}$	22	28.0	41.2	0.68	31	64	189	67
3	5.22	$\frac{3}{4} \times \frac{3}{4}$	31	36.4	45.4	0.80	27	64	219	67
		$\frac{1}{2} \times \frac{1}{2}$	30	34.9	45.1	0.77	28	64	212	58
		$1\frac{1}{2} \times 1\frac{1}{2}$	26	31.6	43.2	0.73	29	62	200	60
4	6.22	$\frac{3}{4} \times \frac{3}{4}$	38	44.2	48.8	0.91	26	64	238	62
		$\frac{1}{2} \times \frac{1}{2}$	35	42.0	48.6	0.86	27	64	233	58
		$1\frac{1}{2} \times 1\frac{1}{2}$	26	33.0	44.3	0.74	28	63	211	58
5	8.24	$\frac{3}{4} \times \frac{3}{4}$	38	44.0	50.2	0.88	26	63	243	57
		$\frac{1}{2} \times \frac{1}{2}$	35	43.9	50.3	0.87	26	63	242	54
		$1\frac{1}{2} \times 1\frac{1}{2}$	32	42.6	50.4	0.84	27	59	240	52
(b) Steels containing Carbon 0.3, Manganese 0.8 per cent.										
7	3.00	$\frac{3}{4} \times \frac{3}{4}$	40	48.0	54.2	0.89	21	62	261	58
		$\frac{1}{2} \times \frac{1}{2}$	34	38.0	47.8	0.80	23	66	231	61
		$1\frac{1}{2} \times 1\frac{1}{2}$	29	33.6	45.5	0.73	25	63	217	59
8	4.00	2×2	28	32.0	44.2	0.72	25	63	206	63
		$\frac{3}{4} \times \frac{3}{4}$	47	51.7	57.4	0.90	22	61	271	39
		$\frac{1}{2} \times \frac{1}{2}$	42	50.0	56.2	0.89	22	62	271	39
9	4.97	$1\frac{1}{2} \times 1\frac{1}{2}$	37	47.0	55.6	0.85	21	55	261	37
		2×2	30	37.4	48.3	0.77	23	57	232	35
		$\frac{3}{4} \times \frac{3}{4}$	46	52.8	57.9	0.91	21	61	277	39
10	5.98	$\frac{1}{2} \times \frac{1}{2}$	45	52.3	57.6	0.90	22	62	277	39
		$1\frac{1}{2} \times 1\frac{1}{2}$	42	50.2	56.6	0.89	21	59	272	35
		2×2	36	46.0	53.9	0.85	22	52	260	33
11	6.99	$\frac{3}{4} \times \frac{3}{4}$	46	52.6	57.6	0.91	22	64	277	39
		$\frac{1}{2} \times \frac{1}{2}$	45	52.0	57.3	0.90	22	62	277	40
		$1\frac{1}{2} \times 1\frac{1}{2}$	45	51.6	57.1	0.90	20	55	273	34
12	8.06	2×2	41	50.0	55.8	0.90	20	56	266	31
		$\frac{3}{4} \times \frac{3}{4}$	47	52.4	57.7	0.91	22	64	281	43
		$\frac{1}{2} \times \frac{1}{2}$	44	52.0	57.6	0.90	22	62	280	41
12	8.06	$1\frac{1}{2} \times 1\frac{1}{2}$	44	52.0	57.8	0.90	21	56	279	34
		2×2	40	51.5	57.4	0.90	21	56	279	32
		$\frac{3}{4} \times \frac{3}{4}$	45	53.0	58.8	0.90	22	64	285	44
12	8.06	$\frac{1}{2} \times \frac{1}{2}$	44	52.8	58.8	0.90	22	62	284	41
		$1\frac{1}{2} \times 1\frac{1}{2}$	43	52.8	58.8	0.90	22	58	283	34
		2×2	42	52.0	57.9	0.90	22	58	280	33

TABLE IX. (continued).
INFLUENCE OF NICKEL (continued).

Steel No.	Nickel %	Cross-Section. In.	Elastic Limit. Tons per sq. in.	Yield Point. Tons per sq. in.	Maximum Load. Tons per sq. in.	Yield Ratio.	Elongation. %	Reduction of Area. %	Average Brinell Hardness Number.	Average Izod Impact Figure. Ft.-lb.
(c) Steels containing Carbon 0.4, Manganese 0.4 per cent.										
13	4.13	$\frac{3}{4} \times \frac{3}{4}$	44	50.4	55.8	0.90	22	58	267	40
		$\frac{3}{4} \times 1\frac{1}{2}$	40	44.9	53.7	0.84	21	54	260	42
		$1\frac{1}{2} \times 1\frac{1}{2}$	32	34.8	48.0	0.73	22	55	224	43
14	5.13	2×2	30	31.5	48.0	0.70	20	51	223	39
		$\frac{3}{4} \times 1\frac{1}{2}$	45	50.9	56.3	0.90	22	59	270	38
		$1\frac{1}{2} \times 1\frac{1}{2}$	38	46.8	54.8	0.85	21	55	258	35
15	6.07	2×2	34	38.0	50.2	0.76	22	55	234	41
		$\frac{3}{4} \times 1\frac{1}{2}$	47	53.0	58.9	0.90	20	60	282	36
		$1\frac{1}{2} \times 1\frac{1}{2}$	45	52.2	58.7	0.89	20	55	280	33
16	7.16	2×2	41	50.6	57.5	0.88	20	55	274	28
		$\frac{3}{4} \times 1\frac{1}{2}$	46	53.4	59.0	0.91	22	58	284	35
		$1\frac{1}{2} \times 1\frac{1}{2}$	44	52.9	58.9	0.90	20	54	281	34
17	8.06	2×2	41	52.0	57.8	0.90	19	55	277	29
		$\frac{3}{4} \times 1\frac{1}{2}$	45	54.2	59.5	0.91	21	58	287	35
		$1\frac{1}{2} \times 1\frac{1}{2}$	42	52.9	59.0	0.90	20	55	282	33
		2×2	40	52.6	58.6	0.90	19	55	280	30
(d) Steels containing Carbon 0.4, Manganese 0.8 per cent.										
18	3.19	$\frac{3}{4} \times 1\frac{1}{2}$	43	50.0	57.7	0.87	22	61	270	40
		$1\frac{1}{2} \times 1\frac{1}{2}$	32	36.6	50.3	0.73	21	52	235	42
		2×2	31	34.9	49.6	0.70	21	53	230	40
19	4.17	$\frac{3}{4} \times 1\frac{1}{2}$	46	52.6	59.2	0.89	20	61	285	34
		$1\frac{1}{2} \times 1\frac{1}{2}$	39	51.6	59.2	0.87	20	55	282	29
		2×2	34	42.6	54.0	0.79	19	51	255	31
20	5.08	$\frac{3}{4} \times 1\frac{1}{2}$	49	56.0	61.1	0.92	20	61	290	34
		$1\frac{1}{2} \times 1\frac{1}{2}$	46	53.8	59.6	0.90	20	55	284	28
		2×2	43	52.6	59.0	0.89	19	51	281	23
21	7.20	$\frac{3}{4} \times 1\frac{1}{2}$	45	57.0	64.1	0.89	20	52	303	30
		$1\frac{1}{2} \times 1\frac{1}{2}$	44	56.6	63.6	0.89	19	51	302	26
		2×2	43	56.8	63.5	0.89	18	47	302	24

INFLUENCE OF CARBON.

Steel No.	Carbon. %	Cross-Section. In.	Elastic Limit. Tons per sq. in.	Yield Point. Tons per sq. in.	Maximum Load. Tons per sq. in.	Yield Ratio.	Elongation. %	Reduction of Area. %	Average Brinell Hardness Number.	Average Izod Impact Figure. Ft.-lb.
(e) Steels containing Manganese 0.3 to 0.45, Nickel 4 per cent.										
22	0.15	$\frac{3}{4} \times \frac{3}{4}$	23	27.8	35.2	0.79	36	75	165	113
		$\frac{3}{4} \times 1\frac{1}{2}$	23	27.8	35.4	0.79	35	75	165	107
		$1\frac{1}{2} \times 1\frac{1}{2}$	17	25.2	33.8	0.79	37	74	158	104
23	0.24	$\frac{3}{4} \times \frac{3}{4}$	27	30.7	39.9	0.76	31	69	190	93
		$\frac{3}{4} \times 1\frac{1}{2}$	27	30.4	40.0	0.76	31	68	186	75
		$1\frac{1}{2} \times 1\frac{1}{2}$	23	28.0	38.5	0.73	33	67	176	77
24	0.31	$\frac{3}{4} \times \frac{3}{4}$	31	34.0	45.7	0.74	27	65	212	69
		$\frac{3}{4} \times 1\frac{1}{2}$	29	33.0	44.4	0.74	28	64	204	59
		$1\frac{1}{2} \times 1\frac{1}{2}$	26	31.5	44.0	0.72	28	62	199	61
25	0.43	$\frac{3}{4} \times \frac{3}{4}$	40	44.0	52.4	0.84	24	57	250	49
		$\frac{3}{4} \times 1\frac{1}{2}$	38	42.2	51.9	0.81	24	58	246	39
		$1\frac{1}{2} \times 1\frac{1}{2}$	29	35.0	49.0	0.72	27	56	224	43
26	0.56	$\frac{3}{4} \times \frac{3}{4}$	46	50.0	57.5	0.87	21	55	272	35
		$\frac{3}{4} \times 1\frac{1}{2}$	44	48.9	57.2	0.86	21	52	269	29
		$1\frac{1}{2} \times 1\frac{1}{2}$	35	39.0	52.2	0.75	23	52	252	30

TABLE IX. (continued).
INFLUENCE OF CARBON (continued).

Steel No.	Carbon. %	Cross-Section. In.	Elastic Limit. Tons per sq. in.	Yield Point. Tons per sq. in.	Maximum Load. Tons per sq. in.	Yield Ratio.	Elongation. %	Reduction of Area. %	Average Brinell Hardness Number.	Average Izod Impact Figure. Ft.-lb.
(f) Steels containing Manganese 0.8, Nickel 4 per cent.										
27	0.21	$\frac{3}{4} \times \frac{3}{4}$	39	46.2	51.7	0.89	23	65	248	54
		$\frac{3}{4} \times 1\frac{1}{2}$	37	42.6	49.3	0.86	24	68	241	59
		$1\frac{1}{2} \times 1\frac{1}{2}$	33	37.0	45.0	0.82	25	68	215	63
28	0.33	2×2	30	34.0	43.0	0.79	26	69	207	62
		$\frac{3}{4} \times \frac{3}{4}$	45	51.8	57.6	0.90	21	62	275	40
		$\frac{3}{4} \times 1\frac{1}{2}$	44	51.0	57.3	0.89	21	64	272	39
		$1\frac{1}{2} \times 1\frac{1}{2}$	37	43.8	52.4	0.84	21	58	251	40
		2×2	34	39.0	49.8	0.78	21	60	241	33
29	0.47	$\frac{3}{4} \times \frac{3}{4}$	47	55.0	62.3	0.88	21	55	296	34
		$\frac{3}{4} \times 1\frac{1}{2}$	46	54.8	62.4	0.88	20	55	296	35
		$1\frac{1}{2} \times 1\frac{1}{2}$	43	53.8	60.3	0.89	20	50	289	30
		2×2	38	45.0	57.3	0.79	19	49	276	30
30	0.55	$\frac{3}{4} \times \frac{3}{4}$	47	56.0	63.7	0.88	19	52	304	28
		$\frac{3}{4} \times 1\frac{1}{2}$	45	56.2	64.0	0.88	19	51	304	29
		$1\frac{1}{2} \times 1\frac{1}{2}$	44	55.2	63.3	0.87	18	49	302	25

INFLUENCE OF MANGANESE.

Steel No.	Manganese. %	Cross-Section. In.	Elastic Limit. Tons per sq. in.	Yield Point. Tons per sq. in.	Maximum Load. Tons per sq. in.	Yield Ratio.	Elongation. %	Reduction of Area. %	Average Brinell Hardness Number.	Average Izod Impact Figure. Ft.-lb.
(g) Steels containing Carbon 0.4, Nickel 4 per cent.										
31	0.09	$\frac{3}{4} \times \frac{3}{4}$	29	32.4	45.2	0.72	26	56	209	53
		$\frac{3}{4} \times 1\frac{1}{2}$	28	31.6	44.1	0.72	26	57	206	43
32	0.13	$1\frac{1}{2} \times 1\frac{1}{2}$	26	30.2	44.1	0.68	26	45	205	49
		$\frac{3}{4} \times \frac{3}{4}$	30	32.5	44.9	0.72	27	57	210	56
		$\frac{3}{4} \times 1\frac{1}{2}$	27	31.3	43.9	0.71	27	58	203	56
33	0.32	$1\frac{1}{2} \times 1\frac{1}{2}$	26	30.0	44.0	0.68	26	52	202	53
		$\frac{3}{4} \times \frac{3}{4}$	31	33.8	47.6	0.71	25	56	220	47
		$\frac{3}{4} \times 1\frac{1}{2}$	30	32.9	46.4	0.71	25	57	217	44
34	0.43	$1\frac{1}{2} \times 1\frac{1}{2}$	25	30.6	45.4	0.67	26	57	214	46
		$\frac{3}{4} \times \frac{3}{4}$	40	43.6	51.8	0.84	23	57	248	50
		$\frac{3}{4} \times 1\frac{1}{2}$	31	34.9	49.2	0.71	24	57	229	51
35	0.56	$1\frac{1}{2} \times 1\frac{1}{2}$	24	32.7	48.4	0.68	26	55	224	46
		$\frac{3}{4} \times \frac{3}{4}$	42	45.8	53.6	0.85	23	57	255	53
		$\frac{3}{4} \times 1\frac{1}{2}$	38	43.3	53.2	0.81	22	57	255	53
		$1\frac{1}{2} \times 1\frac{1}{2}$	36	43.1	53.2	0.81	21	57	252	52
36	0.80	3 diam.	24	30.9	46.0	0.67	25	57	210	49
		$\frac{3}{4} \times \frac{3}{4}$	45	49.7	56.7	0.88	22	58	270	45
		$\frac{3}{4} \times 1\frac{1}{2}$	44	48.7	56.1	0.87	22	58	268	44
		$1\frac{1}{2} \times 1\frac{1}{2}$	39	46.7	56.3	0.83	21	57	268	45
37	0.94	2 diam.	34	41.6	53.5	0.78	22	55	253	44
		$\frac{3}{4} \times \frac{3}{4}$	47	51.0	57.9	0.88	21	57	276	49
		$\frac{3}{4} \times 1\frac{1}{2}$	46	49.6	57.1	0.87	22	55	273	46
		$1\frac{1}{2} \times 1\frac{1}{2}$	39	47.4	56.8	0.83	20	47	273	48
		2 diam.	38	47.0	56.4	0.83	20	46	272	47
		3 diam.	33	38.0	50.6	0.75	24	58	236	45

TABLE IX. (continued).
INFLUENCE OF CHROMIUM.

Steel No.	Chromium. %	Cross-Section. In.	Elastic Limit. Tons per sq. in.	Yield Point. Tons per sq. in.	Maximum Load. Tons per sq. in.	Yield Ratio.	Elongation. %	Reduction of Area. %	Average Brinell Hardness Number.	Average Izod Impact Figure. Ft.-lb.
(h) Steels containing Carbon 0.4, Manganese 0.4, Nickel 4 per cent.										
13	Nil	$\frac{3}{4} \times \frac{3}{4}$	44	50.4	55.8	0.90	22	58	267	40
		$\frac{3}{4} \times 1\frac{1}{2}$	40	44.9	53.7	0.84	21	54	260	42
		$1\frac{1}{2} \times 1\frac{1}{2}$	32	34.8	48.0	0.73	22	55	224	43
42	0.15	2×2	30	34.5	48.0	0.72	20	51	223	39
		$\frac{3}{4} \times \frac{3}{4}$	47	53.0	59.2	0.90	21	57	286	37
		$\frac{3}{4} \times 1\frac{1}{2}$	45	53.0	59.6	0.89	21	55	276	34
43	0.22	$1\frac{1}{2} \times 1\frac{1}{2}$	34	41.0	53.4	0.77	20	56	251	34
		2×2	31	37.0	51.2	0.72	20	52	246	33
		$\frac{3}{4} \times \frac{3}{4}$	48	54.6	60.3	0.91	20	57	293	34
		$\frac{3}{4} \times 1\frac{1}{2}$	45	53.6	60.6	0.89	20	55	284	31
		$1\frac{1}{2} \times 1\frac{1}{2}$	40	47.0	56.7	0.83	20	56	267	31
		2×2	32	41.0	52.6	0.78	20	54	252	27

In Table X. are given the properties of some steels of different sections tempered to give approximately the same maximum load, and the results illustrate the persistence of mass effect even when the hardness difference is eliminated. The effect is shown by the lower elastic limit, yield ratio, elongation, reduction of area, and impact figures given in each case by the larger section.

TABLE X.—Properties of Steels of Different Sections, Oil-Hardened from 850° C. and Tempered to give the Same Maximum Load.

Steel No.	Cross-Section. In.	Tempering Temperature (2 hours). ° C.	Elastic Limit. Tons per sq. in.	Yield Point. Tons per sq. in.	Maximum Load. Tons per sq. in.	Yield Ratio.	Elongation. %	Reduction of Area. %	Average Izod Impact Figure. Ft.-lb.
28	$\frac{3}{4} \times 1\frac{1}{2}$	600	40	46.4	52.4	0.89	22	65	50
	$1\frac{1}{2} \times 1\frac{1}{2}$	550	37	43.8	52.4	0.84	21	58	40
29	$\frac{3}{4} \times 1\frac{1}{2}$	600	41	48.4	56.0	0.86	22	59	45
	2×2	550	38	45.0	57.3	0.79	19	49	30
42	$\frac{3}{4} \times 1\frac{1}{2}$	630	35	42.8	52.0	0.82	24	62	46
	2×2	550	31	37.0	51.2	0.72	20	52	33
43	$\frac{3}{4} \times 1\frac{1}{2}$	630	35	42.9	52.6	0.82	24	62	46
	2×2	550	32	41.0	52.6	0.78	20	54	27

MICROSTRUCTURE.

The microstructures of steel 34, containing carbon 0.38, manganese 0.43, and nickel 3.97 per cent., after oil-hardening from 850° C. and tempering at 550° C. in sections of various sizes, are shown in Figs. 21 to 23 (Plate XI.). With an increase in section

there is a corresponding increase in the amount of ferrite which has separated during quenching. This ferrite separation occurs under the conditions of composition and section represented by the lower part of the hardness curves in Fig. 20; the upper part of these curves, beyond the steep slope, is associated with more uniform structures such as that shown in Fig. 21. The properties associated with the structures are given in Table IX. (steel 34).

The effect of increased manganese content in suppressing the separation of ferrite in sections $1\frac{1}{2}$ in. square is shown in Figs. 23 and 24, while the similar effect of increasing nickel content in steels with low manganese is shown in Figs. 25 to 28 (Plate XII.). In these steels, with increasing nickel content, quenched as $\frac{3}{4} \times 1\frac{3}{4}$ -in. sections, there is a rapid increase in hardness between 5 and 6 per cent. of nickel (Fig. 17, curve 3), and this is accompanied by the disappearance of the ferrite network, as will be seen by a comparison of Figs. 26 and 27.

SUMMARY AND CONCLUSIONS.

The properties of nickel steels containing carbon 0.2 to 0.55 per cent. and nickel 3 to 12 per cent. have been examined, with special reference to the effect of manganese.

1. The critical ranges of these steels have been determined. Ac_1 is lowered by about 10° C. for each 1 per cent. of nickel. In nickel steels with 3 to 5 per cent. of nickel, cooled at a rate of 4° C. per minute, the Ar_1 point is lowered by an amount varying with the manganese and carbon content from 25° to 30° C. for each 1 per cent. of nickel.

2. In nickel steels with low manganese contents there is no advantage in increasing the nickel beyond 6 per cent., on account of the limitation imposed on the tempering temperature by the lowering of Ac_1 . For a similar reason with higher manganese (0.8 per cent.) no advantage is gained by exceeding 4.5 per cent. of nickel.

3. The effect of manganese up to 0.8 per cent. on the critical ranges of nickel steel is small. An increase of manganese from 0.4 to 0.8 per cent. in steels with about 4 per cent. of nickel causes a fall in Ac_1 of 3° C. and a similar fall in Ar_1 when the rate of cooling is about 4° C. per minute.

Chromium produces a decided rise in Ac_1 even when present in small quantities; 0.22 per cent. of chromium raises Ac_1 by $7^\circ C.$, though it has little effect on Ac_3 , Ar_3 , or Ar_1 .

4. The effect of manganese in maintaining increased hardness of 3 to 4 per cent. nickel steel at slow rates of cooling becomes most evident when 0.5 per cent. of manganese is exceeded. When both manganese and chromium are present the influence of the chromium in this respect is nearly twice as great as that of manganese.

5. An increase of manganese in 3 to 4 per cent. nickel steels leads to an improvement in the elastic limit and yield point without loss of ductility. A sudden marked improvement becomes evident at a manganese content which is greater the larger the section treated.

6. A nickel steel which, on account of its section, has received inadequate hardening may, after tempering, show the desired hardness and tensile strength; but when it is compared with a steel which has been efficiently hardened and subsequently tempered to give the same tensile strength, the mass effect will still be evident in lower elastic limit, yield ratio, elongation, reduction of area, and impact figures.

These effects are due structurally to the separation of ferrite during hardening, and to the incomplete suppression of the pearlite change.

7. Manganese has a marked influence on the mass effect in 3 to 4 per cent. nickel steel. A low-manganese steel will not harden satisfactorily even in very small sections. The amount of manganese necessary to secure adequate hardening varies with the size of section treated, but in no case should it be less than 0.5 per cent. A manganese content of 0.8 per cent. is an advantage in securing good tensile properties in large masses, and is preferable to an increase in carbon content above 0.4 per cent. On the other hand, a very high manganese content involves susceptibility to temper-brittleness, which has to be guarded against in heat treatment.

The author wishes to express his gratitude to Dr. R. H. Greaves for his continual interest and encouragement during the progress of this work.

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DISCUSSION.

Mr. T. M. SERVICE (Glasgow) said he had read the paper with very great interest, and it confirmed the work he had done in that connection relative to the effect of manganese on nickel steels. He entirely agreed with the work the author had done up to the limit of the mass on which he had carried out his experiments; but to larger masses he was afraid the experiments did not extend. He took exception to some of the statements in the author's conclusions, in one of which he said the manganese content should not be less than 0.5 per cent. In making nickel steel pinions it was quite customary—in fact, it was general practice—to use less than 0.5 per cent. of manganese and to get all the results that were asked for, namely, high elongation and high Izod figures. It was true there was a certain amount of ferrite present in the structure, but it was not sufficient to affect the mechanical tests. He had also tried a higher manganese content, keeping the nickel and carbon the same as in the 0.4 per cent. steel, and it was his experience when taking transverse tests, as everyone had to do in pinions, that the reduction of area, the elongation and the Izod were reduced with the higher manganese. If there were plenty of length work and only length tests were taken, the figures agreed with Mr. Jones' results, but in the transverse direction they did not. He did not think, therefore, the statement should be allowed to pass that the minimum manganese content in steel should be 0.5 per cent. He thought it was necessary for each manufacturer to work out the manganese content for himself, having regard to the tests which the engineer specified.

Mr. A. P. HAGUE (Chesterfield) supported Mr. Service in his remarks regarding manganese, especially in cases where a mass over, say, 10 in. in diameter was being dealt with. There could be no doubt in practice that 0.4 up to 0.55 per cent. of manganese was far better than 0.55 up to 0.8 per cent., which one would infer from the paper should be the case. In making pinion forgings they were called upon to meet an Izod test of 35 ft.-lb. If the manganese was round about 0.8 per cent. very great difficulty was experienced in obtaining that figure, but if the manganese was down to 0.4 per cent. no difficulty was experienced in getting 60 ft.-lb.; so that from the practical point of view he was afraid he did not agree with the conclusions in the paper. With regard to ferrite, it was stated—and there was a lot in it—that the best impact was obtained from a purely sorbitic steel, and that if ferrite was present the impact figure was reduced. He had rarely seen micrographs from test-pieces of pinion forgings of an ordinary size, from, say, 20 to 24 in. in diameter in the barrel, which had given 50 ft.-lb. and had not contained a considerable amount of free ferrite; that again hardly agreed with the author's conclusions.

Dr. W. H. HATFIELD (Member of Council) agreed with what Mr. Service and Mr. Hague had said with regard to the limit of value of manganese. Those engaged in industry certainly could not accept the suggestion that the amount of manganese used could not be under 0.5 per cent. The paper contained a lot of extremely interesting data concerning compositions, but they related to heat treatment on a very small scale. He suggested that if, prior to publishing his conclusions, the author had visited Sheffield and Glasgow and had consulted Mr. Service and others on his conclusions, they would have explained to him the inadvisability of putting forward such limits. One point of very great consequence which the author had not envisaged, and which neither Mr. Service nor Mr. Hague had mentioned, was that when nickel was added to steel—or chromium—it was for the purpose of hardening and tempering large masses of steel. It was undoubtedly a fact that if the manganese were run high, as the author suggested, there would be a much greater facility for cracking, a thing to be avoided at all costs. He therefore suggested to the author that, in making recommendations in regard to specifications for the analysis of special steels, practical considerations of manufacture should be considered before proposals of that kind were put forward. The manufacturers of those steels must be credited with having explored the ground with an assiduity equal to the author's, while at the same time they were able to take note of the additional facts which bore on the practical side of the industry.

Professor J. H. ANDREW (Glasgow) thought that, from the practical point of view, it must be accepted that the author had presented a number of experimental facts which, it must be admitted, were correct for the particular steels which the author had treated. The author, however, very carefully avoided any theoretical considerations. He showed very clearly that if steel were tempered at a temperature which was slightly within the Ac_1 range an increased hardening was obtained. He desired to ask whether the author could give any figures showing the effect of manganese and nickel on the width of the Ac_1 range, and also whether he had any theory to explain the hardening obtained when he heated up to a temperature just within the Ac_1 range. Dr. Dickie and he (Professor Andrew) had published some time ago a theory on that very question, and, although the author had mentioned that particular paper, he very carefully avoided any reference to the theory; personally, nothing would please him better than to know that the author could provide a better theory.

CORRESPONDENCE.

Dr. H. A. DICKIE (Glasgow) wrote that he had recently carried out some thermal work on commercial and non-commercial nickel steels of compositions similar to some of those used by Mr. Jones. From the results of that work he was in a position to confirm much of Mr. Jones' thermal work. A summary of the temperatures of the critical points in six nickel steels was given in Table A below. In those experiments the rates of heating and cooling were much quicker than those used by Mr. Jones. The rate of heating was about 50°C . per minute near Ac_1 , and the rate of cooling similar above Ar_3 . The quicker heating had not made much appreciable difference in the position of the heating points, but the quicker cooling rate, together with the higher initial temperature in some cases, had delayed the Ar thermal changes considerably.

TABLE A.

Steel.	Analysis. Si, S, P low, omitted.				Ac_1 start. $^{\circ}\text{C}$.		Ac_1 max. $^{\circ}\text{C}$.	Ac_3 end. $^{\circ}\text{C}$.	Initial Temp. of Cooling Curves. $^{\circ}\text{C}$.	Ar_3 max. $^{\circ}\text{C}$.	Ar_1 max. $^{\circ}\text{C}$.
	C. %	Mn. %	Ni. %	Cr. %	A.	B.					
					Between						
CN2	0.15	0.46	1.96	...	695 and 700	705	715	830	950	691	618
CN3	0.12	0.63	2.80	0.38	685 „ 690	698	715	806	850	674	577
CN5	0.10	0.40	4.86	0.23	675 „ 680	680	698	768	850	612	460
3N	0.33	0.51	3.28	...	675 „ 680	685	709	752	900	625	588
E92	0.24	0.22	5.13	...	665 „ 670	674	691	765	900	612	559
E331	0.22	0.16	6.96	...	655 „ 660	660	667	730	900	559	510

Column A : temperature of start of Ac_1 revealed by heating steel at progressively rising intervals of 5°C . followed by cooling curves.

Column B : temperature estimated as showing the beginning of heat absorption at Ac_1 on an inverse-rate heating curve.

There was one important respect, however, in which his (Dr. Dickie's) results showed apparent disagreement with those of Mr. Jones, namely, in the temperature of the start of the Ac_1 range. For example, the steels 3N and E92 were similar in composition to Mr. Jones' steels Nos. 1 and 3, and the Ac_1 maxima were in close agreement. He (Dr. Dickie) found, however, that Ac_1 did not commence until temperatures of above 675° and 665°C . for steels 3N and E92, as against Mr. Jones' determinations of 648° and 624°C . for steels Nos. 1 and 3. The small difference in manganese content between steel 3N and steel

No. 1, and the small difference in carbon content between steel *E92* and steel No. 3, could not be held to account for such a marked difference in the temperatures of the start of Ac_1 . The results for the other steels point to a similar discrepancy in all cases.

In the course of considerable experience of the determination of the commencement of Ac_1 in nickel and other steels he (Dr. Dickie) had found that the best method of determination was to heat at progressively increasing soaking temperatures and take a cooling curve after each soaking treatment. It was essential to avoid any superheating of the specimen during the heating-up by insulating it well from the furnace wall and by heating very slowly, particularly in the last 50° C., or so. If those conditions were not strictly observed, it was possible to heat the surface of the specimen to a higher temperature than that desired without the excessive temperature being revealed by the thermocouple, the junction of the latter being embedded in the specimen. The liability to such undesired overheating was much increased should the thermo-junction not be firmly in contact with the specimen. A superficial change might thus be brought about which would give an increase in hardness on quenching. That increased hardness was apparent even after grinding off the tarnished surfaces of the specimen, but when the specific volume was determined in addition to the hardness it was seen from the contraction obtained that the main mass of the specimen had not reached the Ac_1 range.

The results in Table A, column A, were obtained by the thermal method described above, and they confirm similar results previously published.¹

On heating a nickel steel to just below the start of Ac_1 and taking a cooling curve down to 30° C., no point or discontinuity was revealed. When the tempering temperature was raised 5° C. for the next treatment, causing some solution of carbide in γ -iron, the cooling curve showed a marked critical point or range. The temperature of that depended on the composition of the eutectoid solid solution formed at the beginning of Ac_1 , and in the case of 3 and 5 per cent. nickel steels was about 450° and 570° C. respectively.

That method of experiment had several advantages over other methods of which he (Dr. Dickie) had had experience, namely, determination of hardness, specific volume, specific resistance, and mechanical properties, together with micro-examination. Effects due to spheroidisation of carbide (giving contraction, softening, and decrease in resistance), and solution of carbide in ferrite (giving expansion, hardening, and increase in resistance), were eliminated, as they were not shown up by an inverse-rate curve. The absorption of heat due to solubility of carbide in ferrite might, however, affect the apparent start of Ac_1 as judged by a differential curve.

In his experience, he (Dr. Dickie) had found that the Ac_1 range did not actually commence until very nearly the temperature which would

¹ Andrew and Dickie, *Journal of the Iron and Steel Institute*, 1927, No. I. p. 647.

be estimated as showing the commencement of absorption of heat at Ac_1 on an inverse-rate heating curve, taken at a heating rate of about 50°C. per minute. In a few steels the difference might be as much as 15°C. , but in most steels it was less than 10°C.

That thermal method had also the great advantage of throwing light on the redistribution of constituents taking place in the Ac_1 range. That subject, with particular reference to nickel steels, had already been dealt with in a joint paper with Dr. Andrew.¹

With the exception of the temperatures given for the start of Ac_1 , which he (Dr. Dickie) felt reluctantly obliged to question, Mr. Jones' paper contained a wealth of data which should be of much use to practical heat-treaters and in future scientific investigations.

This paper was presented at the adjourned meeting held in Sheffield on May 10, 1928. The following remarks are extracted from the discussion which took place :

Mr. T. P. COLCLOUGH (Rotherham) congratulated the author on a paper of extreme value to all working with or studying nickel steels. The data presented gave, so far as they went, a very representative and reliable account of the tests which could be obtained with the varying compositions studied, and the results were in accord with those obtained in commercial practice.

Before the data could be accepted as the basis for specifications for commercial steel, it was, however, necessary to direct attention to two factors which had a very marked effect on the production of those steels for engineering purposes. The general conclusion to be drawn from the paper was that it was desirable to specify for the 3 per cent. nickel steels a manganese content in the region of 0.8 per cent., the purpose being to delay the carbon transformation on cooling and produce greater hardness. While that *might* be desirable in larger masses, it was decidedly *undesirable* in certain classes of work of small cross-section.

It was well known that the retardation of the carbon transformation caused a great tendency to cracking during the quenching operation of 3 per cent. nickel steels in the form of small rounds, and, further, that that tendency was accentuated by an increase of the manganese content. With 0.8 per cent. of manganese the losses in that operation would be largely increased without any corresponding improvement in the quality of the steel.

A similar situation arose in the manufacture of thin sections or plates. In that case machining operations had to be carried out on the steel in its normalised condition. With a manganese content such as 0.8 per cent. there was grave danger of local hardening in parts which cooled rapidly on withdrawal from the furnace, and that inevitably led to increased costs in machining.

The data contained in Table IX. regarding the effect of chromium,

¹ *Loc. cit.*

even within the limits of the S9 specification, were particularly valuable as throwing light on the variations possible in those steels with similar treatment.

In order to maintain a due sense of proportion in studying the problem of nickel steels, it was essential that those points of practical manipulation should be considered.

The above data had, in the main, been established for a considerable period in steelworks research departments, but there were other directions in which the author could give valuable information. Reliable data were still lacking for the physical constants, such as coefficients of expansion, &c., for various temperatures and varying compositions of the steels in question. Such information was of first-rate importance in studying questions of warping, tolerances in hot pressing, &c., and it was to the national research organisations that one looked for such data.

Mr. G. STANFIELD (Sheffield) said there was one practical aspect of the subject which he thought required more consideration, namely, the liability of the steels to crack in heat treatment. The author rather favoured the use of an increased manganese content in 3 to 4 per cent. nickel steels, and reported negligible trouble from cracking in the experimental work. Cracking in hardening was, however, a frequent source of trouble with nickel and nickel-chromium steels, and small surface irregularities, due to scaling and other causes, were liable to lead to wastage by cracking. Consequently, all precautions had to be taken to keep such losses to a minimum. The rectangular and square sections used by the author were a favourable feature from that point of view. Probably, also, he had the advantage of using machined bars. The general indications were that liability to cracking was associated with high manganese content. That, however, could not be directly established, and proof on the point could only be provided by a statistical study. The case appeared to him (Mr. Stanfield) to be sufficiently definite to warrant keeping the manganese content in the region of 0.5 per cent., unless very enhanced properties were to be gained by going higher. He considered that the desired mass effect could be obtained in the steel by an increase of the nickel content, which did not appear liable to lead to the same troubles.

Mr. JONES replied that he was very glad to have confirmation of the results from Mr. Service, at least up to the limit of mass dealt with. He was careful in preparing the paper to make it clear that his recommendation in regard to a low limit of manganese content of 0.5 per cent. was based purely on the question of mass effect. He proposed shortly to put forward some further results which would show the same effect in forgings up to a wall thickness of 10 to 12 in. When the manganese was low the mass effect was much more pronounced than when the manganese content was about 0.8 per cent.

He had also guarded against the low impact figure which might be obtained when the manganese was increased to 0.8 per cent., by saying, "A very high manganese content involves susceptibility to temper-brittleness, which has to be guarded against in heat treatment." That applied to the remarks of Mr. Hague, who stated that when the manganese was high a low Izod figure of 35 was obtained compared with a high Izod figure of 60 when it was low. He suggested that the low figure was not due to the deleterious effect of manganese on the impact figure in itself, but was probably due to its effect in inducing temper-brittleness. He realised that any great increase in manganese content might involve some difficulties in regard to the susceptibility of the steel to cracking, as pointed out by Dr. Hatfield, but during the course of this work he had only met with cracks in one steel (No. 30).

With regard to Professor Andrew's question as to the effect of manganese on the widening of the range, the only results he had available were those which he had communicated in connection with the paper to which Professor Andrew had referred.

The apparent discrepancies mentioned by Dr. Dickie, in the temperature given for the beginning of the Ac_1 range, arose from the fact that it varied with the method of determination. If determined as the point at which a change of direction occurred on a heating curve, it might be only a few degrees below Ac_1 (max.); if determined by the dilatometer it would be lower; if determined by Dr. Dickie's method it would be still lower (but even in that case it was dependent on the sensitivity of a cooling curve), and lowest of all if determined by the methods indicated in the paper. It was considered that from the practical heat-treatment standpoint that was the correct method of determination, as it fixed the temperatures above which tempering treatments should not be carried out.

The paper was not meant to refer to nickel steels in the soft condition, and the conclusions only applied when the full benefit of an oil-hardening treatment was desired and a combination of high yield point and ductility were required. Other alloy steels intended to give such properties were equally liable to present the difficulties pointed out by Mr. Colclough and Mr. Stanfield. He disagreed with Mr. Stanfield in the suggestion that high nickel was equally effective in overcoming mass effect. His experience was that at least an additional 1.5 per cent. of nickel would be required to produce the effect equivalent to an additional 0.4 per cent. of manganese.

THE INFLUENCE OF NICKEL ON IRON-CARBON-SILICON ALLOYS CONTAINING PHOSPHORUS.¹

BY ARTHUR B. EVEREST, PH.D.,

AND

PROFESSOR D. HANSON, D.Sc.
(BIRMINGHAM).

INTRODUCTION.

IN a recent paper ² the influence of nickel and silicon on an iron-carbon alloy containing about 3.5 per cent. of carbon was investigated, and certain conclusions were drawn thereon. Whereas the alloys used might be described as being of the same type as the cast irons, they should not be confused with the commercial cast irons, since they were made from specially pure pig iron—American washed iron—and were prepared under conditions very different from those of commercial iron practice. Moreover, they were practically free from certain elements, notably phosphorus and manganese, which are invariably found in commercial irons.

Further experiments have now been carried out, in which phosphorus has been added to the variable factors, principally with the object of ascertaining how the effect of nickel on such alloys is altered by phosphorus.

In the first place, experiments were made on synthetic alloys simulating cast iron, using American washed iron as base, and the results are described in Section I. of this paper. Some repeat tests were afterwards made, using a commercial refined iron as base, and these are described in Section II. The work has been carried out on a laboratory scale at the University of Birmingham, all melts being made in a gas-fired crucible furnace. It should be stated that the alloys used are not necessarily commercial cast

¹ Received February 28, 1928.

² A. B. Everest, T. H. Turner, and D. Hanson, "The Influence of Nickel and Silicon on an Iron-Carbon Alloy," *Journal of the Iron and Steel Institute*, 1927, No. II. p. 185.

irons, and the results must be interpreted with regard to the experimental conditions under which they were obtained.

SECTION I.—THE INFLUENCE OF NICKEL ON SYNTHETIC ALLOYS.

The American washed iron used as the basis of these experiments had a total carbon content of about 3.5 per cent. The general practice adopted was to melt the iron and add the silicon as 97 per cent. silicon ; phosphorus was then added as 20 per cent. ferro-phosphorus crushed into small lumps, less than the size of a pea. This did not go into solution very easily, and it was found necessary with the higher phosphorus additions to maintain the melt at a high temperature in the furnace for about twenty minutes, stirring at intervals, before all the ferro-phosphorus was dissolved. Finally, nickel as required was added as " F " shot, as described in the previous paper.

Composition of Alloys Cast.—Two silicon and three phosphorus concentrations were selected for the tests, as follows :

Silicon, 1.2 and 2.5 per cent.

Phosphorus, 0.2, 0.5, and 1.2 per cent.

Irons of six compositions were thus obtained. One pot, containing 18 lb. of metal, was made up to each composition, and four castings were made from each pot. The castings were made up to the following percentages of nickel : 0, 1, 2, and 3 per cent. The nickel additions were made between castings, as described in the report on the influence of nickel and silicon on an iron-carbon alloy. Twenty-four castings were thus obtained, giving six series with varying silicon and phosphorus, with four nickel contents in each series.

In all cases the pouring temperature was 1320° C., and no difficulty was experienced in obtaining good sound castings. Coloured skins on the castings were associated with the high-phosphorus alloys.

Form of Casting.—A step-bar casting was again employed for the tests, but the form of casting was modified, as indicated in Fig. 1, in accordance with the suggestion of Mr. J. E. Fletcher, to whom the authors' thanks are due. During casting the mould was inclined so as to place the $\frac{1}{8}$ -in. step at a slightly lower level

than the 1-in. step. To obtain some quantitative measurements of chill, a small cast-iron chill was moulded in at the tip of the $\frac{1}{8}$ -in. step, as shown in Fig. 1. The total weight of this casting, with its runner and riser, was 4.3 lb. The moulds were made up of greensand and skin-dried. The castings were allowed to cool

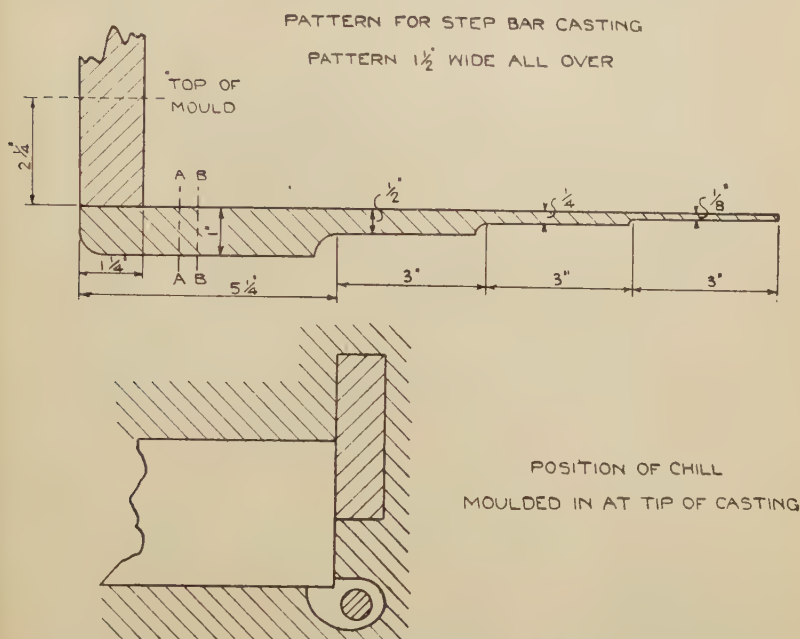


FIG. 1.—Details of Modified Step Bar.

in the moulds, and when cold were knocked out, scratch brushed, and trimmed.

The castings were cut across at *AA* and *BB*, the runner being scrapped. The piece between *AA* and *BB* was used for micro-examination.

Experimental Results.

Analyses of Castings.—It has not been considered necessary to perform complete analyses of the castings, determinations being made only of the elements known to vary.

Experience from previous work shows that, under the conditions of these tests, the total carbon remains constant at about 3.5 per cent., sulphur remains constant at about 0.03 per cent., and there is no manganese present. This was confirmed on castings Nos. P10 and P20, in which the amount of sulphur was found to be 0.03 and 0.029 per cent. respectively, while only a trace of manganese was present.

In Table I., recording the analysis on 1-in. sections of castings of the metal in each pot, the combined carbon is given for the casting containing no nickel. Silicon and phosphorus have each been determined on at least two castings in each series, and the figures given represent the mean value.

The agreement between the actual and intended figures for silicon and phosphorus is reasonably good, in view of the variable loss sustained in adding these elements to small quantities of the original iron. The influence of phosphorus in raising the combined carbon is very marked in the case of the low-silicon irons. This point is significant in connection with the chill and hardness results dealt with later.

TABLE I.—*Analysis of the Base Metal of each Series.*

	P1.	P2.	P3.	P4.	P5.	P6.
	%	%	%	%	%	%
Combined carbon . .	1.38	1.51	1.65	1.17	1.18	1.22
Silicon—intended . .	1.2	1.2	1.2	2.5	2.5	2.5
Silicon—actual . . .	1.19	1.19	1.195	2.40	2.48	2.61
Phosphorus—intended .	0.2	0.5	1.2	0.2	0.5	1.2
Phosphorus—actual . .	0.185	0.535	1.26	0.175	0.477	1.274

Nickel Determinations.—Experience has shown that there is no loss of nickel when it is added to crucible melts, and the agreement between calculated and actual nickel contents can be relied on to be good. However, it was decided to check some of the nickel results, and accordingly determinations were made on the third casting of each series, that is, on the casting intended to contain 2 per cent. of nickel, with the following results :

Casting.	P12.	P22.	P32.	P42.	P52.	P62.
Nickel content . . .	1.97	1.96	1.93	1.94	1.95	1.99 per cent.

Fracture and Chill.—The $\frac{1}{4}$ -in. and $\frac{1}{8}$ -in. steps of each casting were broken across in order to examine the variation in fracture

throughout the series. The results of the examination of the fractures of the low-silicon irons are given in Fig. 2, which diagram is self-explanatory.

Where a series of grey fractures was obtained through the addition of nickel, as in the $\frac{1}{4}$ -in. step of the series containing 0.2 per cent. of phosphorus, a slightly finer grain was observed with increasing nickel content.

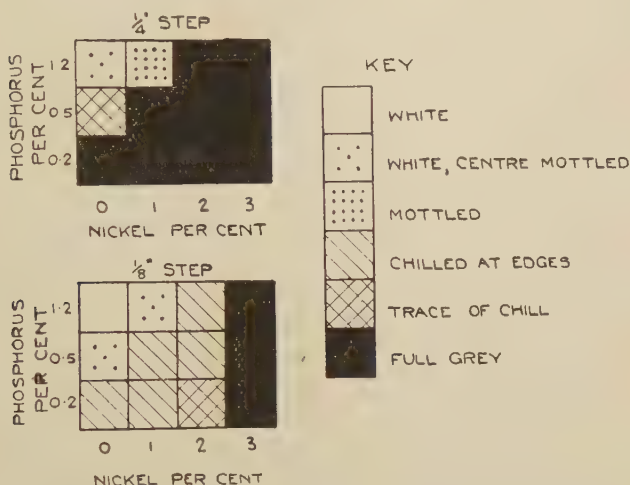


Fig. 2.—Fractures in Low-Silicon Irons. Silicon, 1.2%.

The diagram for the $\frac{1}{8}$ -in. step emphasises the strong influence of phosphorus on the chill of the low-silicon iron, but indicates also that the presence of nickel effectively counteracts this influence. Phosphorus does not have so marked an effect in the case of the higher silicon irons (Si 2.5 per cent.). All the fractures of the $\frac{1}{4}$ -in. steps were grey, and in each series a slight but definite refining of the grain was obtained on the addition of nickel. The $\frac{1}{8}$ -in. steps showed a slight chill at the edges of the low-nickel specimens. Quantitative measurements of the chill are given in Fig. 3.

Chill measurements were made on the longitudinal fracture of the $\frac{1}{8}$ -in. step from the end of the step cast against the chill.

The position of the curve for the 0.5 per cent. phosphorus irons is somewhat anomalous in the case of each silicon content.

The curves are much as would be expected, and agree with the previous observations on chill depicted in Fig. 2, showing a marked increase in chill in the presence of phosphorus, this chill again being reduced by the addition of nickel.

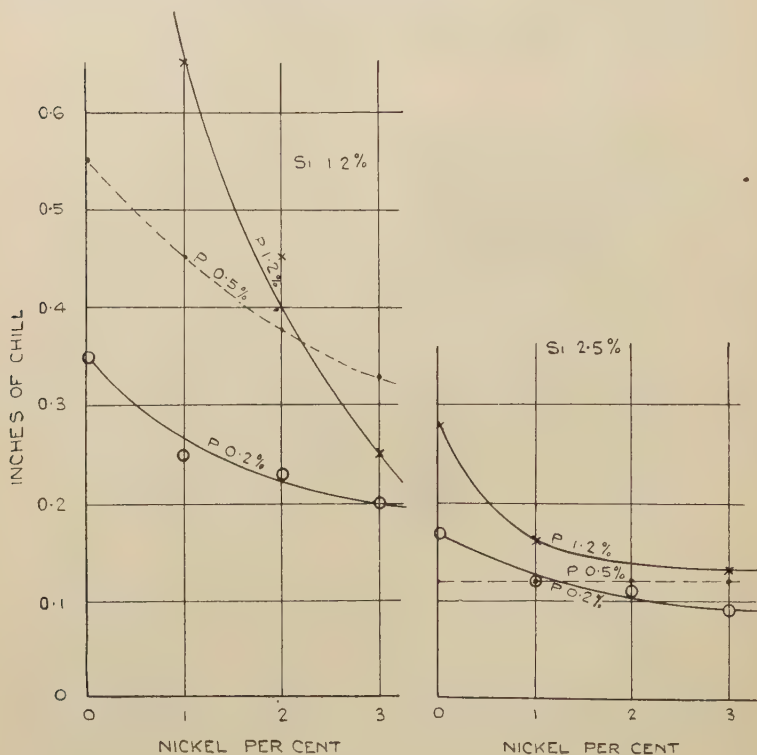


FIG. 3.—Depth of Chill.

Machinability.—Phosphorus has a very marked influence on the machinability of the irons used in these experiments, this probably being associated with the high combined carbons in the series.

Series P1, with 1.2 per cent. of silicon and 0.2 per cent. of phosphorus, could be readily cut with a hack-saw, nickel in this series having a slight but definite tendency to improve the machinability when 2 or 3 per cent. was present.

Series P2, with 1.2 per cent. of silicon and 0.5 per cent. of

phosphorus, however, proved much more difficult to cut, but the higher nickel specimens showed improved machinability.

Series P3, with 1.2 per cent. of silicon and 1.2 per cent. of phosphorus, was quite unmachinable in the original form, and specimens from castings P30 and P31 had to be cut on the carborundum cutting-wheel. Specimens P32 and P33, however, with 2 per cent. and 3 per cent. of nickel were capable of being cut, but with very great difficulty, on a good machine saw.

Series P4 and P5 in the higher silicon series, each with 2.5 per cent. of silicon, and containing 0.2 and 0.5 per cent. of phosphorus respectively, proved machinable, though the machinability of the latter was not good. The specimens in series P6, with 1.2 per cent. of phosphorus, had to be cut on a special machine saw, being machinable only with difficulty. In all cases nickel improved the machining qualities, though its influence was not very great. This can readily be understood, since nickel appears to have no influence on the phosphide eutectic, which by its presence impairs the machinability of the iron.

Hardness Determinations.—Brinell hardness determinations were made on each step of each casting, employing the 2-mm. diameter ball with a load of 120 kg.; in each case the mean of two or three determinations was taken. Tests were also made on the 1-in. and $\frac{1}{2}$ -in. steps, using a 10-mm. ball with a load of 3000 kg.

The hardness curves are shown in Figs. 4 and 5. Each figure refers to one silicon content and shows the variation of hardness of different thicknesses of the casting with varying nickel and phosphorus.

The three curves in each diagram show the effect of nickel on the iron with the phosphorus fixed at each of the three values given.

In Fig. 4 it will be noticed that increasing nickel hardens the irons in each section for phosphorus contents of 0.2 per cent. and 0.5 per cent. With 1.2 per cent. of phosphorus, however, more rapid cooling in the thinner sections induces chill, which is rapidly counteracted by the addition of nickel, consequently the hardness curve for the 1.2 per cent. phosphorus irons in the thinner sections shows initially a rapid drop on the addition of nickel; but as will be noticed in the curves in Fig. 4c, further additions of nickel harden the iron.

The curves for the $\frac{1}{8}$ -in. step are not included in this diagram,

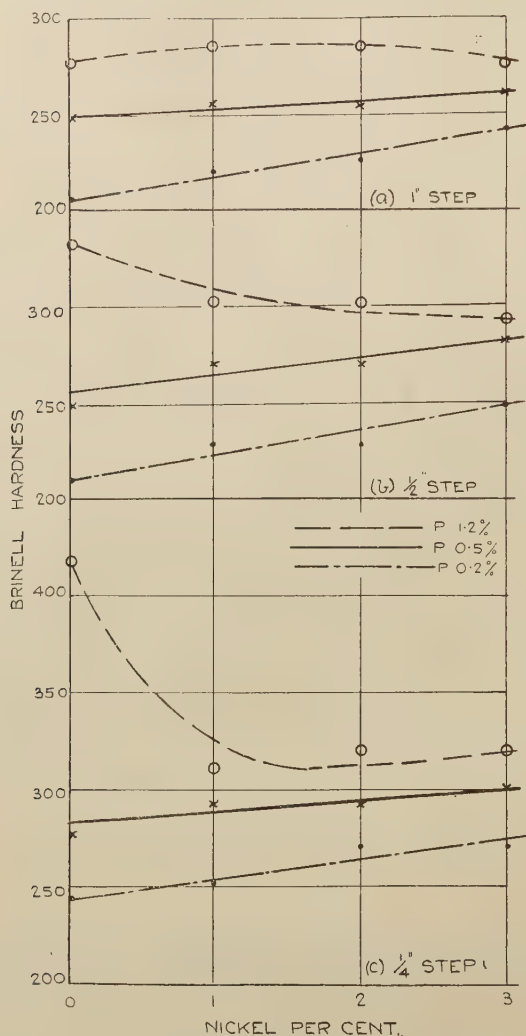


FIG. 4.—Hardness Values with Varying Nickel and Phosphorus. Silicon, 1.2%.

since they are similar to those of the $\frac{1}{4}$ -in. step, the hardness values being approximately identical.

Increasing phosphorus in the irons containing no nickel causes a rapid hardening in the first place, this effect falling off in intensity with higher additions of phosphorus, except where cooling conditions induce chill with these additions. As nickel prevents such chill, phosphorus is seen on the whole to have less action on irons with nickel than on those without.

Fig. 5 shows the corresponding curves for irons with 2.5 per cent. of silicon. This diagram shows none of the chill, indicated in Fig. 3, produced by the presence of phosphorus. Silicon is therefore as effective as nickel in counteracting the chilling influence of phosphorus.

On the other hand, it will be noticed that the curves are grouped much more closely together in diagrams (c) and (d), indicating that the addition of phosphorus has little hardening action on irons cast into thin sections, and therefore subjected to rapid cooling; in fact, a study of diagram (d) shows that the increase in hardness between 0.5 per cent. and 1.2 per cent. of phosphorus is very small.

The rapid increase in hardness of the irons on the addition of phosphorus, indicated in diagrams (a) and (b), is accompanied by a slight increase in the combined carbon in the alloys. Consequently the slight fall in hardness seen in these diagrams on the addition of nickel to 1.2 per cent. phosphorus irons may be due to an increase in the amount of graphite produced by the action of the nickel.

On the other hand, the curves in diagrams (c) and (d) show a uniform rate of increase of hardness on the addition of nickel, irrespective of the initial phosphorus contents (that is, the *slopes* of these curves are identical), indicating that nickel is acting here solely on the matrix of the iron.

Machinability Tests on Phosphorus Series.—Tests were carried out at the works of Messrs. Belliss and Morcom, Ltd., Birmingham, by kind permission of Mr. F. O. Everard, their standard drill hardness test being used.

In this test a drill of standard steel, ground to constant cutting angles in a jig, is forced into the specimen under constant load at a constant speed of revolution. The test drill is $\frac{3}{4}$ in. in diameter, and pressure on its nose is relieved by the prior drilling of a hole $\frac{1}{8}$ in. in diameter, co-axial with the path of the test drill. A curve

is drawn autographically, connecting depth of penetration of the

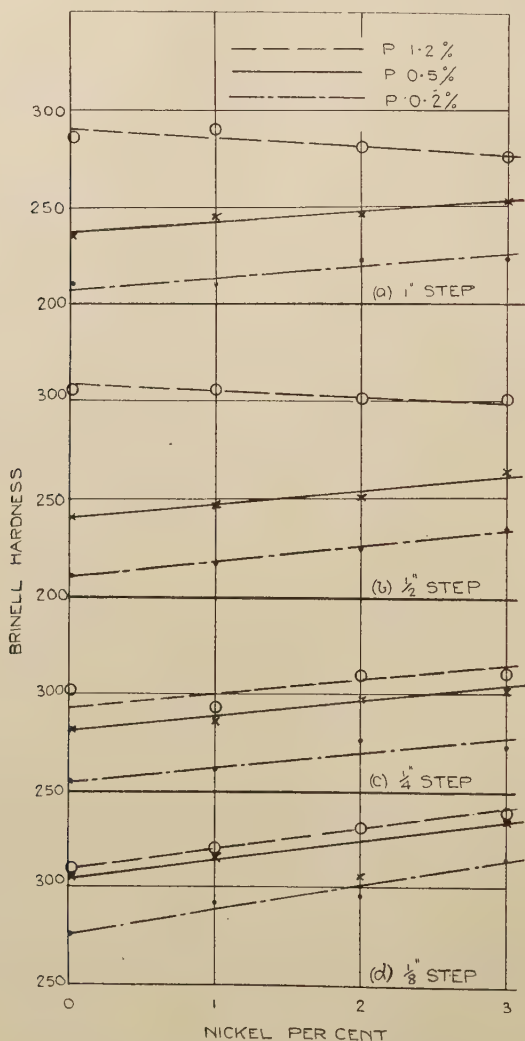


FIG. 5.—Hardness Values with Varying Nickel and Phosphorus. Silicon, 2.5%.

drill with the number of revolutions. The drill hardness numeral is the number of revolutions of the drill required for 1-in. penetration into the specimen.

All the specimens were tested by this method, one hole being drilled into the side of the 1-in. section, a fresh drill being used for each test.

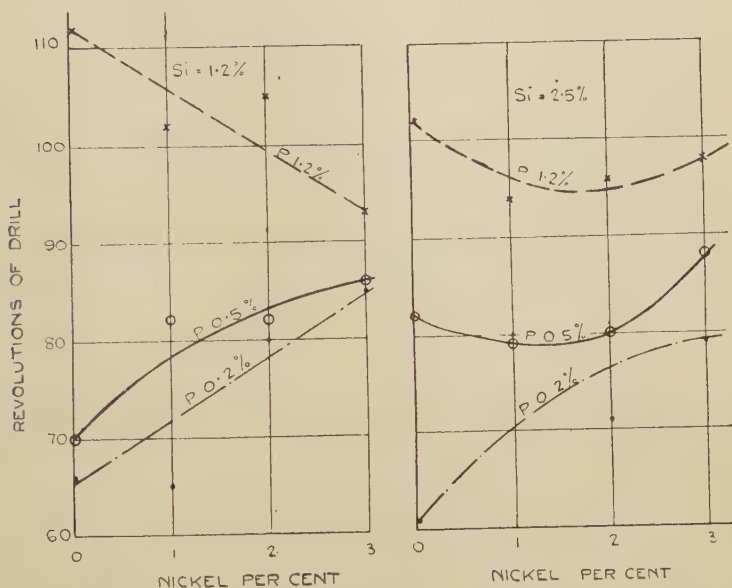


FIG. 6.—Drill Hardness Tests.

The results are presented graphically in Fig. 6. In order to assist in the interpretation of these results, it may be stated that a normal hard iron for heavy steam-engine cylinders requires eighty revolutions of the drill.

Microstructure.

Influence of Phosphorus and Nickel on Graphite.—In the low-silicon irons the graphite is refined by the addition of phosphorus. With 0.2 per cent. of phosphorus the graphite is medium coarse, with 0.5 per cent. it is fine, and with 1.2 per cent. of phosphorus it is in the form of very fine flakes and nodules. The influence of nickel on the graphite is modified by the presence of phosphorus.

With 0.2 per cent. of phosphorus increasing nickel produces a finer form of graphite, this being most marked with 3 per cent.

of nickel. With 0.5 per cent. of phosphorus, 2 per cent. of nickel produces no change in the form or quantity of the graphite. With 3 per cent. of nickel, however, the graphite appears to be somewhat coarsened. With 1.2 per cent. of phosphorus the effect of 1 per cent. and 2 per cent. of nickel is to produce a greater quantity and coarser form of graphite ; with 3 per cent. of nickel the form is somewhat refined.

In connection with these results it is important to remember that the combined carbons for these irons are 1.38, 1.51, and 1.65 per cent. respectively.

As would be expected, higher silicon masks the effects produced by phosphorus, and, in consequence, the influence of nickel on the graphite is less pronounced in the 2.5 per cent. silicon irons. Throughout, the graphite is moderately coarse, and in general occurs in the whorl or rosette form. In series 5 and 6 it was noted that 3 per cent. of nickel gives a finer graphite form, but lower percentages appear to have little or no effect.

Etched Specimens.—Specimens were etched with a 1.5 per cent. solution of nitric acid in alcohol.

In all specimens a phosphide network more or less marked was seen by the naked eye (Fig. 11, Plate XIII.).

Experiments have been conducted with special reagents (modifications of Stead's reagent), with a view to etching the specimens deeply to reveal this network more clearly. These experiments, however, have led to no very satisfactory result ; in the case of the irons under investigation, a carbide network exists owing to the high combined carbon present, and this masks the phosphide network to some extent.

Observations on the network structure revealed by ordinary etching methods show that, with the lower percentages of phosphorus, nickel has no appreciable influence on the size of the structure.

With 1.2 per cent. of phosphorus, however, nickel produces a very marked refining of the network. With 1.2 per cent. of silicon and 3 per cent. of nickel the mean diameter of the cells enclosed by the network is only one-third of that without nickel.

Typical microstructures of irons with each phosphorus content are shown in Figs. 12, 13, and 14 ; nickel has no apparent influence on the form or quantity of the phosphide eutectic.

In all series, nickel produces a finer structure in the pearlite, rendering it in general finely granular or sorbitic, but this effect is more pronounced in the low-phosphorus irons, high phosphorus appearing to mask it. This will be illustrated later.

Again, the development of acicular pro-eutectoid cementite is seen (Fig. 15) in two specimens—*P12* and *P13*—containing 2 per cent. and 3 per cent. of nickel in an iron with 1.2 per cent. of silicon and 0.2 per cent. of phosphorus; this effect is similar to that seen in the corresponding iron with no phosphorus. With 0.5 per cent. of phosphorus, 3 per cent. of nickel has not produced the same effect, nor is acicular cementite seen in any of the other specimens; this clearly indicates that phosphorus masks the effect of nickel, confirming the statement of Houston¹ that more nickel is required to produce a given effect in the presence of high phosphorus than of low phosphorus.

It will be noticed from Table I. that throughout this series of tests the combined carbon in the specimens is very high (between 1.17 and 1.65 per cent.). Part of this combined carbon is undoubtedly associated with the phosphide areas as ternary eutectic² and as excess cementite in this eutectic (Fig. 16, Plate XIV.). But this will account for only a small part of the combined carbon. Consequently there must be a considerable quantity of excess carbide in the pearlite. Examination of the specimens with no nickel at high powers reveals in most cases granular cementite in the pearlite.

It has already been shown that in series *P1* the addition of nickel renders this carbide acicular; in the other series, however, it is found that nickel throws the excess carbide to the grain boundaries in a granular form, while it renders the grain centre uniformly sorbitic (Fig. 17). This effect is more clearly marked in the higher silicon irons, and is clearly seen in series *P4*. Three per cent. of nickel appears to produce in this case excess carbide in a finer form, giving a fine granular structure in the ground-mass of the iron.

The higher silicon series calls for little further comment. The influence of nickel on the pearlite and on the graphite has already

¹ *Iron and Coal Trades Review*, 1927, vol. cxiv. p. 391.

² H. Jungbluth and H. Gummert, "On the Influence of Casting Temperature and Annealing on the Extent and Form of Occurrence of the Phosphide Eutectic," *Kruppsche Monatshefte*, 1926, vol. vii. p. 41.

been discussed. It is seen that there is no marked change in the form of the phosphide areas, although it has been noted elsewhere that in the higher phosphorus series there is a refining in the size of the phosphide network.

Summary of Section 1.

The influence of nickel up to 3 per cent. on synthetic irons containing 1.2 and 2.5 per cent. of silicon, with phosphorus varying between 0.2 and 1.2 per cent., has been studied.

Phosphorus renders the low-silicon iron very susceptible to chill, 1.2 per cent. producing a white fracture in $\frac{1}{8}$ -in. sections of the iron. The addition of small quantities of nickel restores the grey fracture to this iron in all sections by counteracting this tendency to chill.

Phosphorus has less effect on the chill of the high-silicon iron, indicating that silicon, like nickel, opposes the effect of phosphorus. Nickel has a refining action on the size of the grain in the grey fractures of the iron.

A phosphorus content of 0.5 per cent. renders these irons difficult to machine, and 1.2 per cent. renders the low-silicon iron unmachinable and the high-silicon iron almost so.

Nickel has little influence on the machinability in the presence of these amounts of phosphorus. This is easily understood, assuming that the unmachinability is due entirely to the presence of the hard phosphide eutectic, for nickel has little or no influence on the form or distribution of this eutectic. The influence of phosphorus is the more pronounced owing to the high combined carbon in the irons investigated.

Phosphorus hardens both the low- and high-silicon irons. In the former case phosphorus promotes chilling in the thin sections, and this chill is counteracted by the addition of nickel. Under all other conditions nickel exerts its normal hardening action on the matrix of the iron.

Phosphorus reduces the amount of graphite in the low-silicon iron; nickel, on the other hand, will regraphitise this iron. In all irons completely graphitised, nickel will render the graphite form finer.

Nickel acts on the matrix of the iron, rendering the pearlite

finely granular or sorbitic. Pro-eutectoid cementite is rendered acicular only in the case of the low-silicon, low-phosphorus iron. Higher phosphorus appears to mask the influence of nickel on the carbide, and also on the pearlite to some extent, both being rendered finely granular on the addition of nickel to higher phosphorus irons.

SECTION II.—THE INFLUENCE OF NICKEL AND PHOSPHORUS ON A REFINED IRON.

Since the experiments described in Section I., for which American washed iron was used, have given results different from those that might reasonably be anticipated in normal commercial practice, some further experiments have been made using a commercial refined iron as base.

In the following tests all castings have been made from one pig of the refined iron, which showed on analysis: Total carbon 3.05, silicon 1.87, manganese 0.75, sulphur 0.09, and phosphorus 0.24 per cent.

Twelve castings were made in all, by adding 0, 1, 2, and 3 per cent. of nickel to the original iron, and again to the same iron with the phosphorus made up to 0.5 and 1.2 per cent. The method of melting, of making the phosphorus and nickel additions, and of casting was the same as before.

Experimental Results.

Analyses of Castings.—One complete analysis was made on each series—that is, representing each pot of metal. The carbons have also been determined on both the 0 per cent. and 2 per cent. nickel castings. The results of these analyses are given in Table II. In every case drillings were taken from the 1-in. section of the castings.

These analyses show that the phosphorus contents of the irons are very close to those intended. Nickel contents are somewhat low, especially in the case of P92.

The ratio of graphite to total carbon shows that neither phosphorus nor nickel has, in this series of experiments, had any profound influence on the amount of carbon graphitised. In each

case the addition of nickel has increased the ratio, indicating a slight graphitising action. The first additions of phosphorus

TABLE II.—*Analysis of the Base Metal of each Series.*

	P70.	P72.	P80.	P82.	P90.	P92.
	%	%	%	%	%	%
Total carbon . .	3.05	3.00	2.98	2.88	2.90	2.80
Combined carbon . .	0.78	0.70	0.81	0.76	0.74	0.70
Graphite . .	2.27	2.30	2.17	2.12	2.16	2.10
Ratio of graphite to total carbon . .	74.4	76.7	72.8	73.6	74.6	75.0
Silicon . . . .	...	1.87	...	1.77	...	1.71
Manganese . . .	...	0.74	...	0.70	...	0.67
Sulphur . . . .	...	0.085	...	0.091	...	0.08
Phosphorus . . .	...	0.240	...	0.51	...	1.16
Nickel . . . .	...	1.93	...	1.84	...	1.76

have lowered the ratio, while further additions have raised it slightly.

Fracture and Chill.—The $\frac{1}{4}$ -in. step of each casting was broken across and the fracture examined. Casting P70 showed a fracture fine grey in the centre of the step and mottled towards the edges. Castings P80 and P90 showed, in the corresponding positions, white fractures with a trace of mottling in the centre of the step. In each case 1 per cent. of nickel rendered the fracture grey throughout.

The depth of chill from the tip of the $\frac{1}{8}$ -in section was measured, and the results are shown in Fig. 7. Again phosphorus is seen to increase the tendency of the iron to chill, while the influence of nickel in eliminating this chill is even more pronounced in this than in the previous experiment. This confirms the observations on the fractures given above.

All castings were readily cut with a hack-saw on the 1-in. section.

Hardness Determinations.—These were made, as before, on each section of each casting, the mean of two results (or more if there were any discrepancy between the first two results obtained) being taken. In this case a load of 750 kg. was used in conjunction with a ball 5 mm. in diameter. It has been found that this combination gives the best results for cast irons over a range of section varying between 1 in. and $\frac{1}{8}$ in.

The results of these determinations are given in Fig. 8. A comparison with Figs. 4 and 5 shows that phosphorus has exerted a greater hardening action on the thinner sections of the castings of refined iron than it did on the synthetic iron used previously. A very considerable chilling effect due to 0.5 per cent. of phosphorus is shown on the $\frac{1}{8}$ -in. step of the test castings, and to a slight extent also on the $\frac{1}{4}$ -in. steps as found in the castings made

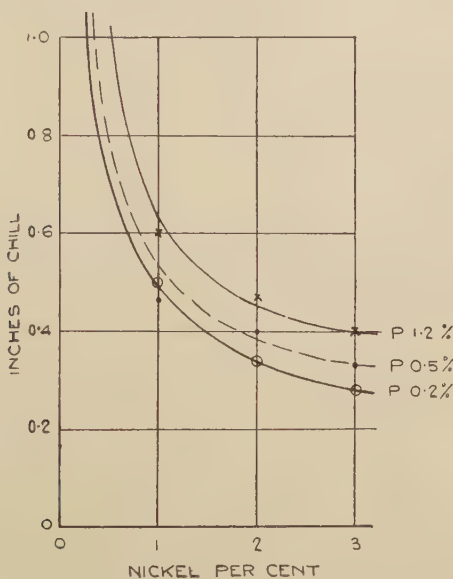


FIG. 7.—Refined Iron. Depth of Chill on $\frac{1}{8}$ -in. Step.

from washed iron. It is clearly demonstrated that 1 per cent. of nickel has in all cases eliminated this hardness produced by chilling.

On the other hand, in the heavier sections, phosphorus has not shown so great a hardening action in this iron. In all cases the hardening action of nickel on the chill-free sections is confirmed.

On the whole, the $\frac{1}{4}$ -in. and $\frac{1}{8}$ -in. sections, as shown in Fig. 8, have a hardness greater even than was the case of the low-silicon synthetic iron (Fig. 4); this is probably due to the lower total carbons occurring in the refined iron.

Drill Hardness Tests.—Tests were carried out exactly as before ; the results are shown by the curves in Fig. 9. There is,

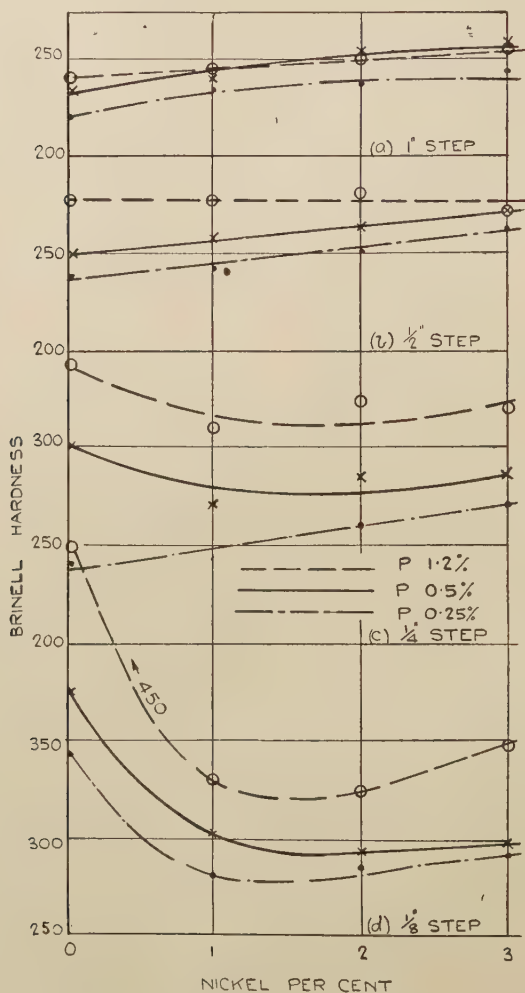


FIG. 8.—Refined Iron. Hardness Values with Varying Nickel and Phosphorus.

on the whole, more regularity in these curves than in those of Fig. 6. The increased drill hardness produced by increasing phosphorus is clearly demonstrated. The addition of nickel up

to 2 per cent. again produces an increase in drill hardness, probably because of its refining action on the matrix of the iron. Three per cent. of nickel, however, in the lower phosphorus series is seen to produce a softer iron in this test than was the case with 1 and 2 per

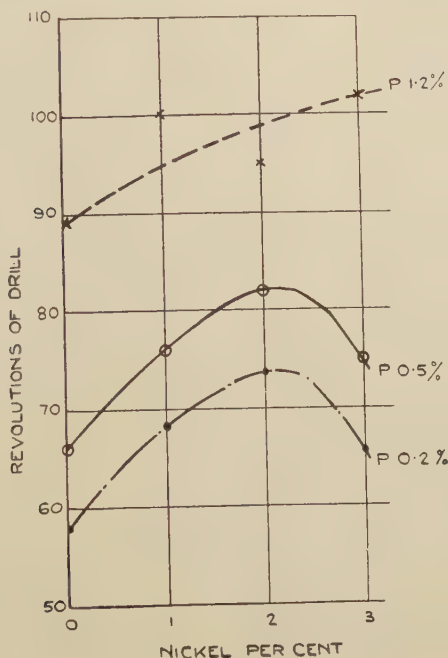


FIG. 9.—Refined Iron. Drill Hardness Tests.

cent. of nickel. This feature is not indicated in the Brinell hardness curves of these irons ; but, as will be shown later, the graphite obtained in the 3 per cent. nickel alloys is appreciably coarser than that obtained with lower percentages of nickel, and this probably has some connection with the changes in drill hardness mentioned above.

With 1.2 per cent. of phosphorus the irons become hard, entering into the ranges of irons not commercially machinable. The influence of nickel in this case does not appear to be so regular, but a general further hardening of the specimens is indicated with increasing amounts.

It is of great interest to note that the Brinell hardness curves for these specimens (1-in. section), as shown in Fig. 8, lie very close together, indicating that there is no direct relation between the drill and Brinell hardness values for this type of material. Phosphorus has a relatively small influence on the Brinell hardness, whereas, perhaps on account of the blunting action of the phosphide eutectic, it has a very pronounced influence on the drill hardness.

Microstructure.

Influence of Phosphorus and Nickel on the Graphite.—The composite micrograph, Fig. 10, illustrates the combined action of phosphorus and nickel on the graphite in the refined iron. As indicated, the horizontal rows represent series with fixed phosphorus and increasing nickel contents.

It will at once be apparent that both nickel and phosphorus separately render the graphite form in the original iron appreciably finer, but consideration of the whole set of micrographs shows that the effect of nickel is less in the higher phosphorus series. The finest graphite is shown with 2 per cent. of nickel and 0.25 per cent. of phosphorus, and it is only in this low-phosphorus series that nickel has a very marked influence on the graphite form. Even in this series, 3 per cent. of nickel appears to have produced a coarser form, confirming observations made on many irons that the maximum refining action of nickel is obtained at about 2 per cent.

Whereas nickel in its action on the iron renders the graphite form very fine, it will be noticed that phosphorus tends to render the graphite form globular. The action of nickel on this form of graphite is only slight. Increasing nickel renders the graphite form finer at 2 per cent. of nickel in the two higher phosphorus series, while in the last series 3 per cent. of nickel appears again to exert a coarsening action.

Etched Specimens.—In the etched specimens the form and distribution of the phosphide eutectic is much the same as in the corresponding phosphorus series in the previous experiments (Figs. 12, 13, and 14).

Examination under higher magnifications shows that in each series the pearlite form is generally continuously refined by the

addition of nickel. An example of this is seen in Figs. 18 and 19 (Plate XIV.), showing specimens containing 0.25 per cent. of phosphorus and 0 per cent. and 3 per cent. respectively of nickel; in the latter case the pearlite is seen to be very finely lamellar.

Increasing phosphorus, however, also influences the form of pearlite, and a finer lamellar form is found in the higher phosphorus

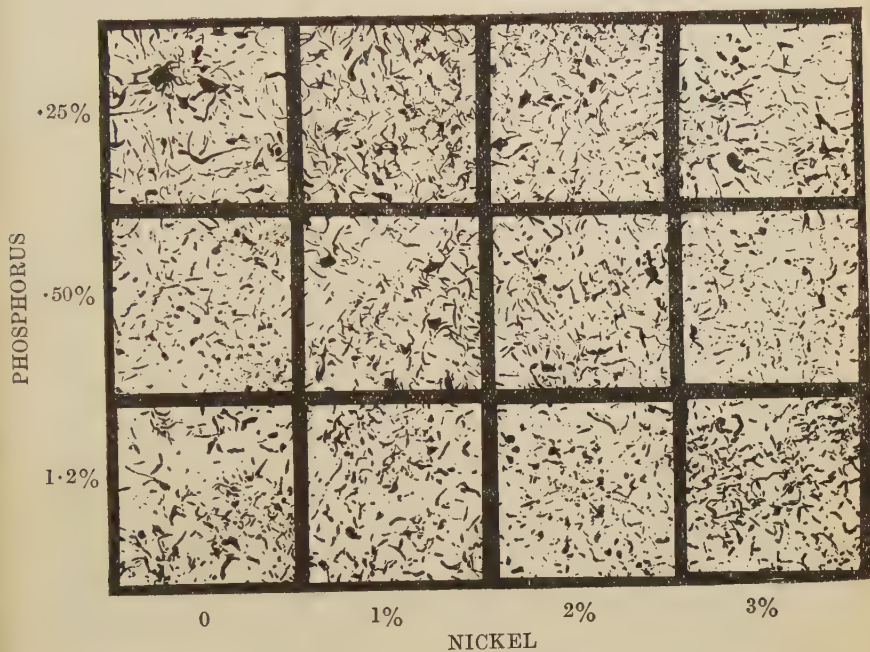


FIG. 10.—Graphite with Varying Phosphorus and Nickel. $\times 25$. (Reduced to four-fifths linear in reproduction.)

series without the addition of nickel (see Fig. 20). The addition of nickel to this iron, however, again causes further refining of the pearlite, which tends in the highest phosphorus series to become locally granular with high nickel.

These observations confirm those made previously on the synthetic alloys, due consideration being given to the silicon content of this iron. It is interesting to note that whereas the graphite is coarser with 3 per cent. than with 2 per cent. of nickel, the pearlite is continuously refined as nickel is increased up to 3 per cent.

Summary of Section II.

The influence of nickel up to 3 per cent. on a refined iron containing 1.87 per cent. of silicon, with phosphorus varying between 0.25 and 1.2 per cent., has been investigated in order to confirm the conclusions drawn from the similar experiments on synthetic irons, using American washed iron as base. The conclusions drawn from Section II. confirm those drawn from Section I.

Phosphorus is found to render the iron very susceptible to chill, again producing white fractures in the $\frac{1}{8}$ -in. sections. With all phosphorus contents, however, 1 per cent. of nickel is effective in counteracting this influence.

Increasing phosphorus rapidly impairs the machinability of this iron, as measured by the drill hardness. Small additions of nickel further increase this drill hardness by hardening the matrix of the iron.

Phosphorus also has a general hardening action on all sections, as measured by the Brinell test. Its action is not very marked, however, on the heavier sections of the castings. Nickel again shows a regular hardening action on all sections, except where chilling the casting has produced white iron, when nickel is effective in softening this iron.

Nickel and phosphorus both show a refining action on the graphite in the iron, but with higher phosphorus the effect of nickel is small, and inappreciable when 1.2 per cent. of phosphorus is present.

Both nickel and phosphorus are shown to induce a finer form in the pearlite.

Conclusions.

Summing up the results in both sections of this work, it is seen that :

Phosphorus increases the hardness of the iron, increases its tendency to chill, and renders it difficultly machinable.

In the absence of chill, nickel produces its normal hardening action. Under conditions likely to produce chilled iron, nickel counteracts the chilling effect of phosphorus.

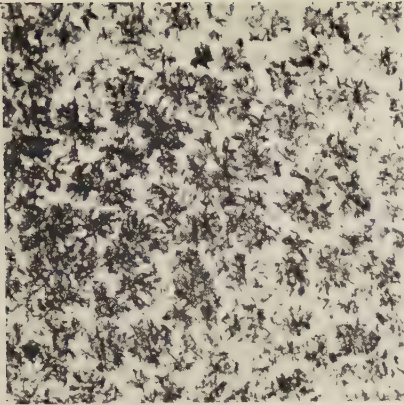


FIG. 11.—Network structure. Silicon 2.5 per cent., Phosphorus 0.5 per cent. $\times 10$.

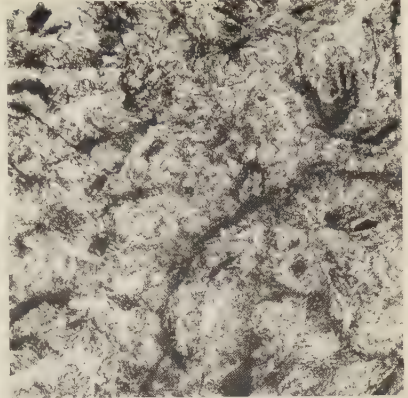


FIG. 12.—Silicon 1.2 per cent., Phosphorus 0.2 per cent. $\times 100$.

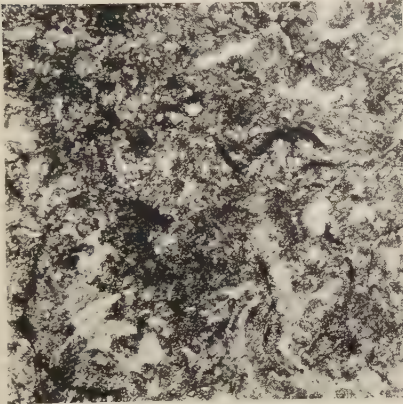


FIG. 13.—Silicon 1.2 per cent., Phosphorus 0.5 per cent. $\times 100$.

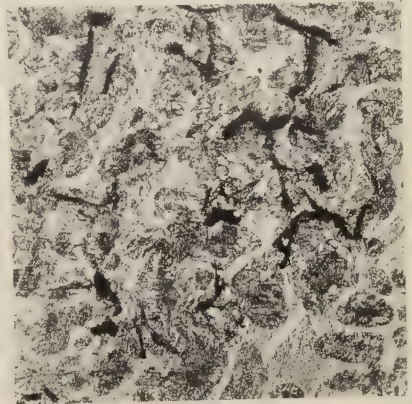


FIG. 14.—Silicon 1.2 per cent., Phosphorus 1.2 per cent. $\times 100$.

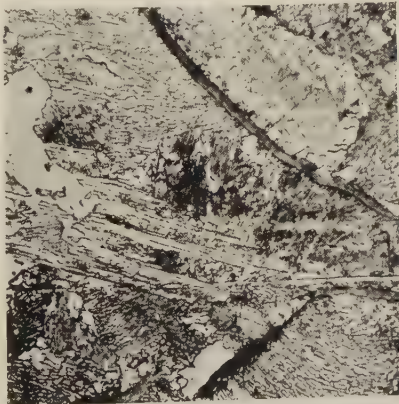


FIG. 15.—Silicon 1.2 per cent., Phosphorus 0.2 per cent., Nickel 3 per cent. $\times 500$.

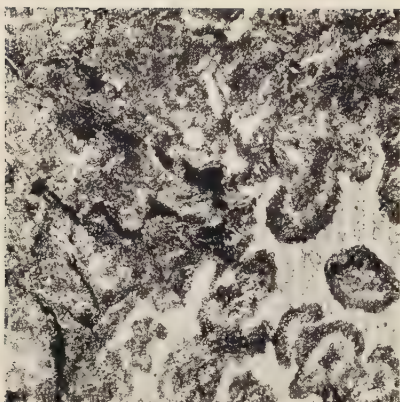


FIG. 16.—Silicon 1.2 per cent., Phosphorus 0.5 per cent. $\times 100$.

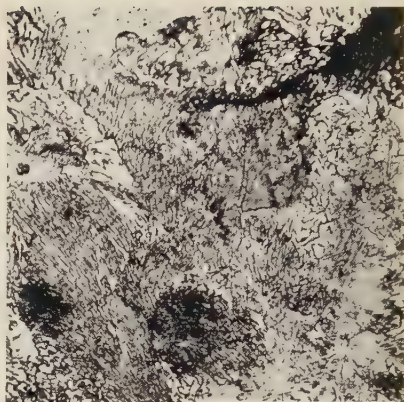


FIG. 17.—Silicon 2.5 per cent., Phosphorus 0.2 per cent., Nickel 3 per cent. $\times 500$.



FIG. 18.—Refined iron. Phosphorus 0.25 per cent., Nickel nil. $\times 500$.



FIG. 19.—Refined iron. Phosphorus 0.25 per cent., Nickel 3 per cent. $\times 500$.



FIG. 20.—Refined iron. Phosphorus 1.2 per cent., Nickel nil. $\times 500$.

The microstructures show that phosphorus tends to reduce the influence of nickel on the iron. More nickel is required to produce a given result in the presence of high phosphorus, where there is any tendency to chill, than would be required in the presence of lower phosphorus.

The authors wish to thank the members of the Nickel Committee of the British Cast Iron Research Association, which has co-operated with them in this work, and in particular Mr. J. G. Pearce, B.Sc., for arranging for some of the chemical analyses to be done in the laboratories of the Association, and Mr. J. E. Fletcher for assistance in designing the step-bar casting. They are also greatly indebted to Mr. F. O. Everard of Messrs. Belliss and Morcom, Ltd., who granted them facilities for carrying out the drill tests for machinability.

DISCUSSION.

Colonel N. T. BELAIEW, C.B. (London), said the authors had referred to the fact that some of the phosphide areas were surrounded by very dense pearlite. In his opinion that very dense pearlite might simply mean that the orientation of the pearlite grains in that particular area was different from the others. When considering pearlite areas in the vicinity of either minute crystals or even of phosphide, it was quite natural to suppose that the orientation would be perpendicular to the other crystals, and that would account to a certain extent for the effect referred to of phosphide areas surrounded by very dense pearlite.

Dr. FRITZ WÜST (Düsseldorf) said he had made some pig iron without using silicon and phosphorus, and he had found that the addition of nickel made the iron very grey. A grey iron was produced having a very high tensile strength of 60 to 70 kg. per sq. mm., and he thought that such an iron might form an excellent material for the manufacture of aero engine cylinders.

Mr. FRANK W. HARBORD, C.B.E. (Past-President), asked whether, in the authors' opinion, the addition of nickel to an iron which was giving satisfactory results—say, a fairly soft silicon iron—would make no appreciable difference. He thought the point was of some importance, because it was known that many silicon irons gave fairly satisfactory chills. As he understood it, the authors were simply replacing silicon by nickel, a much more expensive element.

CORRESPONDENCE.

Mr. E. ADAMSON (Sheffield) wrote: On p. 342 of their paper the authors state that phosphorus in low silicon irons increases the combined carbon. My experience, however, is that in ordinary castings the influence of phosphorus is similar to silicon, but very much weaker. High-phosphorus irons give a lower chill than low-phosphorus irons, and they are greyer, with a slightly lower percentage of combined carbon. Possibly the authors are fully aware that it is not possible to obtain commercially pig irons with ratios of silicon to combined carbon such as they give. *Normally* in a pig iron with 1.0 per cent. of silicon, particularly if the phosphorus be high, the combined carbon will be under 1.00 per cent. This suggests that in Section I. of their

paper there must have been some other influence at work, if increasing phosphorus *per se* increased the combined carbon. The increase in hardness, however, can well be understood by reason of the phosphide being harder than pure iron.

On p. 351 the authors state that there must be a considerable quantity of excess carbide in the pearlite. Are the authors suggesting more than one formula for carbide of iron?

In Section II., p. 360, the authors find that phosphorus renders refined irons susceptible to chill, which is contrary to my experience.¹ Again, the increased hardness is understood.

Generally the authors show the difficulty of one worker agreeing with another if the base is not the same.

Mr. J. SHAW (Sheffield) wrote that he had read the paper with much interest. Unfortunately, owing to the use of a washed iron base, few of the conclusions drawn, before the nickel additions, were such as were found when using straight pig irons. Hence there was some doubt what the effect of nickel would be when alloyed with a phosphoric pig of a similar analysis to the first series. There was now a fair amount of evidence that a pure iron, with its composition drastically raised by concentrated alloys, did not give the same structure or tests as an iron of the same composition straight from the furnace. Homma in a recent paper on "Chilled Castings" found that an iron whose silicon was raised from 0.08 per cent., by means of additions of a 97 per cent. ferro-silicon, to 1.98 per cent. consistently gave higher Shore figures and a much greater percentage depth of chill than another iron which had not been so drastically treated. The details of the two irons were as follows:

A. Total carbon 3.48, silicon 1.67 per cent.	} Only traces of other elements
D. " " 3.78, " 1.98 " (treated iron)	

Iron.	Casting Temperature. ° C.	Shore Values—			Chill Effect. %
		Centre.	Midway.	Edge.	
A	1250	33	35	77	4
D	1250	63	71	77	50
A	1500	35	40	74	16
D	1500	66	75	75	70

Many other examples could be quoted, as, for instance, the authors' own figures:

¹ *Journal of the Iron and Steel Institute*, 1906, No. I. pp. 91, 92, Tables A and B.

	Synthetic Iron.	Refined Iron.	Synthetic Iron.	Refined Iron.	Synthetic Iron.	Refined Iron.
	%	%	%	%	%	%
Total carbon . .	3.50	3.05	3.50	2.98	3.50	2.90
Combined carbon . .	1.17	0.78	1.18	0.81	1.22	0.74
Graphitic carbon . .	2.33	2.27	2.32	2.17	2.28	2.16
Silicon	2.40	1.87	2.48	1.77	2.61	1.71
Manganese	Trace	0.74	Trace	0.70	Trace	0.67
Sulphur	0.03	0.09	0.03	0.09	0.03	0.08
Phosphorus	0.18	0.24	0.48	0.51	1.27	1.16

There, with consistently lower carbons and silicons in the refined iron, the combined carbon was at least one-third lower than in the synthetic iron. With the highest phosphorus there was an actual drop in combined carbon, a result in keeping with ordinary practice, due to the longer freezing range. While, owing to the hardness of the phosphide eutectic, an increase in the Brinell number and hardness might be expected with increasing phosphorus, there was never any difficulty in machining a casting 1 in. thick, with the silicon down to 1.2 per cent. and the phosphorus up to 1 per cent. The following test-bars taken from MacKenzie's paper showed what little effect phosphorus had on the combined carbon, although the hardness was increased; the bars were 2 in. \times 1 in. as against the authors' $1\frac{1}{2}$ in. \times 1 in. :

Total Carbon. %	Silicon. %	Manganese. %	Sulphur. %	Phosphorus. %	Combined Carbon. %	Brinell Hardness Number.
2.96	1.24	0.42	0.048	1.55	0.91	262
3.64	1.29	0.54	0.054	1.51	0.79	228
3.00	0.90	0.46	0.146	3.55	0.56	277
3.78	1.17	0.34	0.061	1.14	0.88	248
3.42	1.19	0.37	0.067	2.25	0.87	286
3.50	0.84	0.42	0.113	2.01	1.09	269
3.25	1.29	0.38	0.049	1.07	0.70	248
3.26	1.26	0.38	0.020	2.09	0.79	277

Those examples could be repeated from other sources.

This criticism was not directed against the authors or scientific research, but against the use of a pure iron base with each element raised by concentrated additions. That method might be quite right for steel, where the metal was reduced to nearly a pure state in each case, and the additions made with concentrated alloys in each case. The reactions being similar, one could look for something like the same results. With cast iron that was not so, and it was known that the results were not comparable, as shown by the authors' own figures.

All recent advances, according to Professor Carpenter's findings, have been made by using a cast-iron base, of which those of Lanz, Emmel, Piwowarsky, &c., are examples.

With regard to the points raised in the paper, it could not be accepted that in the first series the total carbon remained constant at 3·5 per cent. The additions alone in the high nickel, phosphorus, and silicon would reduce it nearly 0·3 per cent. There was also evidence of oxidation if the effect on the refined iron repeated itself. In the latter case the carbon, silicon, and manganese all dropped after allowing for the additions made. To hold 10 lb. of metal in a furnace for 20 minutes with increasing temperatures would also lead to another complication, namely, that that treatment would automatically lead to an increase of combined carbon, even if no oxidation took place, as proved by Piwowarsky and others. He (Mr. Shaw) suggested that the increase of combined carbon was due to those two causes, and not to the increased phosphorus.

He would also suggest that by running their stepped casting from the thin end with a spray the full width of $1\frac{1}{2}$ in. quite a different result would be obtained with the two thin steps. No foundryman, if he could help it, would run through his thickest section to his thinnest section. The metal would be chilled before it reached the thin part.

The AUTHORS, in reply, said they had been particularly pleased to hear Dr. Wüst's contribution to the discussion. The paper represented only a stage in a bigger investigation into the effect of nickel on commercial cast iron.

Mr. Harbord had referred to the effect of nickel on a fairly soft silicon iron already giving satisfactory results. They desired to confirm the statement that the beneficial effect of nickel was best brought out when the silicon content was rather abnormally low, that is, it was not to be expected, so far as could be seen at present, that startlingly beneficial results would be produced by adding nickel to a mixture which was already giving satisfactory service. But there were many irons in which, by reducing the silicon content and replacing it with nickel in suitable proportions, very greatly improved properties could be obtained. Dr. Wüst had instanced a case in which, as they understood Dr. Wüst, the whole of the silicon was replaced by nickel. It was not necessary to go to such extreme lengths as that to get a very greatly improved iron; but they emphasised the point that in making alloy cast iron, whether it were by nickel additions or any other additions, it was essential to modify the composition of the base iron in accordance with the particular alloy that was added. If an alloying element was introduced, then the silicon must be adjusted to be suitable for that alloy addition. An ordinary soft grey iron was not, as a rule, vastly improved by nickel additions, but if the silicon content was reduced below the normal, then the nickel might give a much better result than that given by the original iron. They

(the authors) agreed with Mr. Harbord that the nickel simply replaced some of the silicon; but the replacement of a cheap element like silicon by an expensive element like nickel was justified by the fact that the properties of some of the nickel cast irons were so very much better than could be obtained from ordinary cast iron containing the ordinary amounts of silicon.

Colonel Belaiew had referred to the question of the orientation of pearlite. They did not quite agree with Colonel Belaiew, particularly if Fig. 16 were referred to. The large phosphide area at the bottom right hand of the illustration contained in the middle what was presumably one grain of pearlite, and if that grain were looked at it would be seen that it was entirely surrounded by a dark band. Under the microscope a difference in orientation was not necessarily found. It was simply that the pearlite itself was finer close to the phosphide areas, although more remote from the phosphide areas it became more open.

The authors, in reply to Messrs. Adamson and Shaw, wished to state that they were fully aware of the discrepancies in results obtained on synthetic and normal bases, and it was for that reason that the experiments made on the former were repeated in Section II. of the paper, on a more normal base. It was felt, nevertheless, that those discrepancies were not so great as to show completely reversed effects of an element like phosphorus in the cast iron, as was suggested by both those gentlemen. There was undoubtedly a satisfactory explanation of those varying results obtained on synthetic or special mixtures, and in different engineering practices.

There was a growing conviction among students of cast iron, especially abroad, that the influence of phosphorus was dependent on the initial combined carbon present in the iron. If the combined carbon was above a certain critical value, then the phosphorus increased the hardness and chill in the iron. If, on the other hand, there was free ferrite present, then some at least of the phosphorus entered into solid solution in that ferrite, and produced a completely opposite effect, even tending to induce further graphitisation. Further proof of that theory was required, but it did appear at the moment to agree with and to explain some of the facts, including that that many foundrymen working on light section engineering castings found, like the authors, that increased phosphorus produced greater hardness and chill in their castings. In the light of those remarks it was clear that in the present work the discrepancies mentioned were due initially to the high combined carbons in the case of each iron. That had already been emphasised in the case of the synthetic iron, and was the result of the low total carbon in the case of the refined iron.

The knowledge of the influence of phosphorus was unquestionably in an embryonic state, and it was hoped to pursue the question of nickel and phosphorus further. Meanwhile, however, it was claimed that the results of the influence of nickel on a certain class of iron were indicated, although that class was apparently a very different one

from that falling normally under the experience of Messrs. Adamson and Shaw.

In answer to further points raised by Mr. Adamson, the authors were not suggesting more than one formula for iron carbide, but suggested merely that during the cooling of the primary austenite in the iron, much pro-eutectoid cementite was separated before the formation of the pearlite, giving excess carbide crystals in the pearlite matrix as shown in Figs. 15 and 17.

The reduction in total carbon on the addition of the alloying elements was not as great as Mr. Shaw made out. Calculation showed that whereas the actual dilution effect in the iron caused a reduction in total carbon of nearly 0.3 per cent., nevertheless the equivalent of 0.15 per cent. was added again with the alloying elements. Moreover, long experience in the methods employed in making up the alloys had demonstrated a negligible loss of any constituent by oxidation; also the furnace temperature was maintained as nearly constant as possible, and no variation in chill was anticipated from that source.

The step casting employed in the tests had not been designed and moulded to give a perfect engineering casting; often more was learnt from a bad casting than from a good one, and the step mould was designed to produce castings with their defects emphasised as much as possible. The test was intended to give comparable results, when run under standard conditions, in different irons; and to run it from the thin end would be completely to defeat that object.

THE EFFECT OF SILICON ON TUNGSTEN MAGNET STEEL.*

By J. SWAN, M.MET. (SHEFFIELD).

INTRODUCTION.

CONSIDERABLE prominence ⁽¹⁾ has been given recently to what Evershed termed the magnetic "spoiling" of tungsten magnet steel. He concluded that the normal carbide was decomposed on annealing at temperatures between 800° C. and 1200° C., and that the steel could be restored to its original state by heating to about 1250° C. for a few minutes; no metallographic evidence indicating the nature of the carbide change was, however, presented.

Hultgren ⁽²⁾ showed that a carbide corresponding to the formula WC was formed in steels of certain compositions when they were annealed at suitable temperatures, that this carbide was extremely hard, and that it formed crystals of geometrical symmetry which appeared in section as rectangles and triangles.

PRELIMINARY EXPERIMENTS.

Annealings were conducted on magnet steels of the compositions indicated in Table I. and the results confirmed those of Evershed, showing that the greatest rate of loss of coercive force occurred at 950° to 1000° C., and, further, that this loss was due to the separation of a carbide from solid solution having physical characteristics identical to those of tungsten carbide, WC.

The presence of a large amount of tungsten carbide in a polished microsection is indicated by the matt appearance of the surface (Fig. 1, Plate XV.). Fig. 2 shows the state of decomposition of the carbide in a steel which has been soaked too much during manufacture, and Fig. 3 the same steel after annealing for seven hours at 950° C. Prolonged soaking gives rise to a growth or segregation of the carbide, which is shown in Figs. 4 and 5.

* Received December 1, 1927.

TABLE I.—*Composition of Steels Tested.*

Mark.	Carbon. %	Silicon. %	Manganese. %	Sulphur. %	Phosphorus. %	Tungsten. %	Chromium. %	Nickel. %
<i>G</i>	0.85	0.14	0.18	0.021	0.017	5.62	0.54	Nil
<i>B</i>	0.76	0.14	0.18	0.023	0.018	5.48	0.53	„
23	0.69	0.12	0.04	0.015	0.023	5.36	0.41	„
20	0.78	0.13	0.06	0.015	0.023	5.51	0.44	„
25	0.74	0.13	0.07	0.018	0.021	5.53	0.43	„
<i>VA</i>	0.74	0.25	0.09	0.027	0.022	6.25	0.60	„
<i>VS1</i>	0.80	0.51	0.33	0.025	0.020	6.98	0.54	„
<i>VS2</i>	0.83	1.05	0.34	0.025	0.020	6.85	0.72	0.02
<i>W2</i>	0.60	0.16	0.27	0.044	0.023	5.91	0.09	Nil
<i>W3</i>	0.64	0.18	0.34	0.061	0.022	6.06	0.10	„
<i>MV</i>	0.67	0.12	0.31	...	...	6.97	0.03	„
<i>MA</i>	0.59	0.09	0.30	...	...	6.21	0.05	0.01

Steels of varying carbon and low chromium contents, *W2*, *W3*, *MV*, and *MA*, were annealed for 24 hours at 1000° C. and examined. With the exception of *MA*, which only showed a small amount, they all contained a considerable quantity of the carbide. It is evident, therefore, that less than 1.0 per cent. of chromium has comparatively little effect on the formation of the carbide.

THE EFFECT OF SILICON ON THE FORMATION OF TUNGSTEN CARBIDE.

During the course of experiments on a steel made for standard test purposes, it was discovered that annealing for a long period did not result in the appearance of tungsten carbide in the steel.

The analysis of this steel *VA* is given in Table I. It will be seen that the only significant variable from the preceding analyses likely to prevent or retard segregation of tungsten carbide is silicon, the percentage of that element being nearly doubled—0.25 per cent. as compared with 0.13 per cent. The increase does not seem very much, but it is apparently quite sufficient to retard to a very considerable degree the segregation of tungsten carbide, as shown by microscopic examination. That retarded segregation, and not an absence of tungsten carbide, was produced was proved by the magnetic tests, which showed a loss in coercive force due to annealing. Full details of these

tests are given in Table II. in which interesting points are revealed.

TABLE II.—*Steel VA. Magnetic Tests after Heat Treatment.*

Test No.	Heat Treatment.	$B_{\text{rem.}}$	H_c .	$BH_{\text{max.}}$
V1	* Water-quenched from 775° C. . . .	11,100	66·5	360,000
V2	* " " 790° C. . . .	11,000	63·5	338,000
V3	* " " 805° C. . . .	10,900	65·5	345,000
V4	Oil-quenched from 915° C. . . .	9,950	75·0	336,000
V5	" " 930° C. . . .	9,950	72·0	326,000
V6	" " 945° C. . . .	9,800	71·0	319,000
V7	Heated at 1250° C. for 3 mins., air-cooled, normalised at 750° C., water-quenched from 785° C. . . .	10,900	74·5	340,000
V8	Water-quenched from 785° C. . . .	11,200	62·5	361,000
V9	* " " 785° C. . . .	11,200	61·5	360,000
V11	* Heated at 1020° C. for 5 hrs., normalised at 750° C., water-quenched from 785° C. . . .	11,200	54·0	315,000
V14	* Heated at 1080° C. for 5 hrs., normalised at 750° C., water-quenched from 785° C. . . .	11,200	57·5	345,000
V13	* Heated at 1130° C. for 5 hrs., normalised at 750° C., water-quenched from 785° C. . . .	11,150	65·5	380,000
V15	* Heated at 1180° C. for 5 hrs., normalised at 750° C., water-quenched from 785° C. . . .	11,200	67·5	378,000

* The bar was ground after hardening. V2 and V9 cracked longitudinally.

The tests V8 to V15 were made on a second rolled bar from the same billet. The material for this bar was evidently kept in the reheating furnace rather longer than the first bar, as the coercive force tests V8 and V9 are a few units lower than tests V1, V2, and V3.

Annealing for five hours at 1020° C. and 1080° C. has reduced the coercive force from 62 to 54 and 57·5 respectively, while the same treatment at 1130° C. and 1180° C. resulted in an increase to 65·5 and 67 respectively. It is quite clear, therefore, that 0·25 per cent. of silicon does not stop the formation of tungsten carbide; it only retards its segregation to a very considerable degree.

The highest coercive force given by this steel when water-quenched is obtained by means of a preliminary high-temperature

treatment, but such a treatment does not necessarily appear to give quite the highest BH_{\max} . The high-temperature treatment provides a means of re-dissolving or re-combining the free tungsten carbide. An equal or even a higher coercive force can be obtained by oil-quenching, but the remanence is in general about 1000 units lower, with a resulting lower BH_{\max} value. Oil-quenching is, however, often very useful where cracking or distortion is liable to occur.

Samples of this steel were annealed for 30 and 60 hours at 1000°C ., but micro-examination revealed no definite indications of tungsten carbide segregation. The effect of higher silicon contents was next investigated, to discover whether, in addition to the retardation of the carbide segregation, the actual metastable condition of the carbides could be preserved, so as to eliminate the small amount of "spoiling" which occurs during the manufacture of tungsten magnet steel. Two further steels, VS1 and VS2, were made with approximately 0.5 and 1.0 per cent. of silicon respectively. Their full analyses are given in Table I., and in some respects it is unfortunate that the carbon and tungsten contents were higher than required.

Table III. gives the magnetic test results obtained from the 0.5 per cent. silicon steel with varying heat treatment. The test-bars were, as was the case for all three steels, 0.375 in. in

TABLE III.—*Steel VS1. Magnetic Tests after Heat Treatment.*

Test No.	Heat Treatment.	$B_{\text{rem.}}$	$H_{\text{c.}}$	$BH_{\text{max.}}$
VS 4	Water-quenched from 785°C . . .	10,850	62	384,000
VS 1	" " 805°C . . .	11,100	63	366,000
VS 6	" " 825°C . . .	10,700	64	380,000
VS 7	Oil-quenched from 915°C . . .	9,100	69	316,800
VS 8	" " 930°C . . .	9,100	70	303,600
VS 9	" " 945°C . . .	9,300	68	303,600
VS10	Heated for 5 hrs. at 1000°C ., normalised at 750°C ., water-quenched from 790°C .	11,000	50	304,000
VS14	Heated for 5 hrs. at 1000°C ., normalised at 750°C ., water-quenched from 825°C .	10,200	59	287,000
VS12	Heated for 5 hrs. at 1100°C ., normalised at 750°C ., water-quenched from 790°C .	10,500	58	322,000
VS15	Heated for 5 hrs. at 1100°C ., normalised at 750°C ., water-quenched from 825°C .	10,250	69	343,000
VS13	Water-quenched from 790°C . . .	10,900	67	364,800

diameter by 8 in. long, and were machined from $\frac{3}{4}$ -in. rolled bar. Soaking treatments were given to the test-bars before machining to the required diameter, so that decarbonisation was eliminated. The water-quenched bars were not ground after hardening as in the case of the steel *VA*, although grinding, if carefully carried out, does not appreciably affect the test results. The bars were tested by the ballistic yoke method, and the values of the magnetising force H were directly measured by means of a differential search coil calibrated in a standard solenoid.

Tests *VS10* to *VS15* were made on a second bar rolled at the same time as the first bar. The results of the soaking treatments show that "spoiling" still occurs on annealing at suitable temperatures. Although the BH_{\max} values are equal to those obtained from steel *VA*, the remanence figures are not quite as high.

Table IV. gives the magnetic results obtained from the third steel in the series, containing 1.0 per cent. of silicon.

TABLE IV.—*Steel VS2. Magnetic Tests after Heat Treatment.*

Test No.	Heat Treatment.	$B_{\text{rem.}}$	H_c .	$BH_{\text{max.}}$
<i>R4</i>	Water-quenched from 805° C. . .	10,500	52.0	241,000
<i>R1</i>	" " 825° C. . .	10,550	58.0	330,000
<i>R5</i>	" " 845° C. . .	10,200	61.5	315,000
<i>R6</i>	" " 865° C. . .	9,700	64.5	309,000
<i>R7</i>	Oil-quenched from 915° C. . .	8,600	67.0	268,000
<i>R8</i>	" " 935° C. . .	8,400	66.0	250,000
<i>R9</i>	" " 955° C. . .	8,450	68.0	260,000
<i>R2</i>	Heated for 5 hrs. at 1000° C., normalised at 750° C., water-quenched from 865° C.	9,400	60.0	286,000
<i>R3</i>	Heated for 5 hrs. at 1100° C., normalised at 750° C., water-quenched from 865° C.	9,750	61.5	301,000

It will be noted that there is still a loss in coercive force due to soaking at 1000° C., although it is not so large as in the case of steel *VS1*, the decreases being 64.5 to 60 and 67 to 59 respectively.

Magnetically, steels *VA* and *VS1* are equally good, but it is quite likely that if the latter had had the lower carbon and

tungsten contents of the former it would have given even better results. Steel *VS2* gives inferior results compared with the first two, due in part to the higher silicon, but the high carbon, tungsten, and chromium contents may also have had some effect in the same direction, consequently the effect of the 1.0 per cent. of silicon may have been somewhat masked.

MICRO-EXAMINATION OF THE SILICON STEELS.

It has been stated previously that steel *VA*, containing 0.25 per cent. of silicon, did not show segregation of tungsten carbide after annealing for 60 hours at 1000° C., followed by air-cooling, whereas all other steels examined before steel *VA* did show this phenomenon. Fig. 6 (Plate XVI.) shows the negligible degree of carbide segregation in this steel, and for purposes of comparison Figs. 7 and 8 show that of steel 20 after the soaking periods indicated; etching was carried out electrolytically for two minutes in a normal solution of sodium carbonate.⁽³⁾

Figs. 9 and 10 are micrographs of steel *VS1* after annealing for 30 hours at 1000° C., and of steel *MV* after annealing for 20 hours at the same temperature. The latter steel is included for comparison, because of its equally high tungsten content, but the fact that it contains practically no chromium makes little, if any, difference to the segregation that has occurred, while incidentally it has a lower carbon content than the former steel. If resolved under a higher power, the dark areas in Fig. 10 are seen to consist entirely of collections of tungsten carbide nodules. Fig. 9 also shows small dark areas, which to some extent are associated with a type of non-metallic inclusion. Most of them contain a nodule or crystal of tungsten carbide, some of them a collection of small nodules of the carbide. The amount of free, visible, tungsten carbide in this steel *VS1* is much less than in steel *MV*. Steel *VS2*, after annealing for 30 hours at 1000° C., shows a similar structure to *VS1*, but contains rather more visible tungsten carbide. It is considered that the visible tungsten carbide in steels *VS1* and *VS2* is due to the high carbon and tungsten contents; on the solidification of the steel it either separates as such, or is formed subsequently as a decomposition product from a complex carbide (Hultgren's *Z2* carbide).



FIG. 1.—Steel B, annealed for 24 hours at 1000°C.; air cooled. Unetched. $\times 4$.

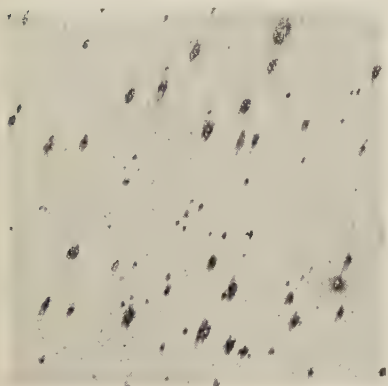


FIG. 2.—Steel 20, as rolled. Unetched. $\times 100$.



FIG. 3.—Steel 20, annealed for 7 hours at 650°C. Unetched. $\times 100$.

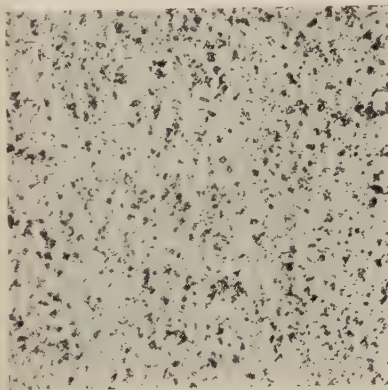


FIG. 4.—Steel G, annealed for 24 hours at 1000°C. Unetched. $\times 250$.

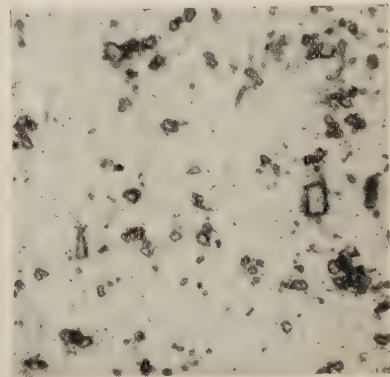


FIG. 5.—Steel G, annealed for 24 hours at 1000°C. Unetched. $\times 1000$.

(NOTE.—FIGS. 4 and 5 reduced to two-thirds linear in reproduction.)

[To face p. 374]



FIG. 6.—Steel VA, annealed for 60 hours at 1000°C. $\times 250$.



FIG. 7.—Steel 20, as received. $\times 250$.



FIG. 8.—Steel 20, annealed for 7 hours at 950°C. $\times 250$.

FIGS. 6-8.—Sections etched electrolytically in a normal solution of Na_2CO_3 .



FIG. 9.—Steel VS1, annealed for 30 hours at 1000°C. $\times 250$.



FIG. 10.—Steel MV, annealed for 20 hours at 1000°C. $\times 250$.

(NOTE.—FIGS. 6-10 reduced to two-thirds linear in reproduction.)

THEORETICAL CONSIDERATIONS.

It is not intended to consider at length the constitution of the tungsten steels dealt with in this paper, for which more evidence may be desirable, but some points may be briefly discussed.

Considering first the tungsten magnet steels with usual silicon contents, 0.13 per cent. and below, and carbon above 0.58 per cent., the "spoiling" of such steels on annealing is due to the formation of tungsten carbide by the decomposition of either, or both, austenite and hyper-eutectoid carbide.

The tungsten carbide so formed is insoluble in austenite at ordinary hardening temperatures, and consequently the steel loses a certain amount of available carbon and tungsten.

As far as the steels containing silicon are concerned, the most reasonable explanation of the great retardation in the carbide segregation appears to be that the solubility of free tungsten carbide in the austenite-silicon solid solution is reduced to a more or less negligible extent. Any carbide then produced by annealing is formed *in situ*, and does not segregate. Such an annealed steel will contain an emulsion of free tungsten carbide, which will not be visible under the microscope. If the tungsten is increased to about 7.0 per cent. with a corresponding rise in carbon from, say, 0.74 to 0.80 per cent., a certain amount of tungsten carbide appears in isolated collections of nodules, and these nodules grow in size to some extent on annealing. Such a growth, however, can be attributed to further decomposition of the double carbide crystallised from the molten phase (Hultgren's Z2 carbide). This carbide is, of course, distinct from the hyper-eutectoid or cementite carbide.

Heating and cooling curves taken on the steels in the normal and annealed states show the magnitude of the critical change point to be less in the latter state, indicating that there is a smaller amount of soluble carbide. Another point of considerable interest is that the steels in the normal condition show under-cooling to the extent of 30° C. at the Ar change, whereas samples previously annealed for 30 hours at 1000° C. only show 1° or 2° C. under-cooling. This suggests that in the annealed condition there is an abundance of carbide nuclei from which precipitation of carbide at the Ar change can commence.

SUMMARY.

The following remarks apply to a magnet steel of normal composition—that is, one containing about 6.0 per cent. of tungsten; not more than 0.74 per cent. of carbon, and 0.0 to 0.6 per cent. of chromium.

1. It has been shown that the “spoiling” of tungsten magnet steel with the usual silicon content of 0.13 per cent. or under by annealing above the Ac point is due to the gradual formation of free tungsten carbide, which is at the most only slightly soluble in austenite at ordinary hardening temperatures, so that the steel loses in available carbon and tungsten contents.

2. The tungsten carbide formed segregates to a marked degree on prolonged soaking, about 20 hours at 980° to 1000° C. being required to produce geometrically shaped crystals of appreciable microscopic size.

3. A silicon content of about 0.25 per cent. and above retards to a remarkable extent the carbide segregation, but does not prevent its formation, since loss in coercive force still occurs on annealing.

4. Silicon up to 0.50 per cent. has no harmful effect on the magnetic properties; it probably has a slight beneficial effect.

5. For the same coercive force as is given by a 0.5 per cent. steel, a silicon content of 1.0 per cent. gives a lower remanence by about 1000 units.

6. The magnetic properties of three steels containing silicon after various heat treatments are given.

CONCLUSION.

When the fact was discovered that a relatively small amount of silicon retarded, or, as it was at first thought, stopped the formation of tungsten carbide, it was hoped that higher percentages would possibly eliminate the “spoiling” effect produced by reheating the steel for rolling or forging. This has not proved to be the case, so that it is still necessary for magnet steel manufacturers to use a maximum reheating temperature for rolling of the order of 1200° C., if the utmost efficiency from tungsten steel is desired. It is true that 1.0 per cent. of silicon reduces

the loss of coercive force on annealing or soaking by about a half, but this is offset by the inferior all-round magnetic properties of the steel, although a steel with lower carbon, tungsten, and chromium contents than those of the author's test-pieces would be expected to give a better result.

The results of a few tests suggest that in the silicon steels the loss due to ageing is considerably less than in steels without an appreciable amount of that element.

The effect of the silicon in retarding tungsten carbide segregation forms a basis for the explanation of the larger volume change on hardening tungsten die steel, which results in the progressive contraction of the bore of circular drawing dies on repeated quenching, a property so much desired by users.

The author wishes to express his thanks to Mr. J. H. S. Dickenson, F.Inst.P., for his interest in the work ; to Mr. Huxley, A.R.S.M., F.I.C., for the chemical analyses ; and to the Directors of Messrs. Vickers, Limited, for permission to publish the results of this investigation, which was carried out in the Vickers Research Laboratories at Sheffield.

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DISCUSSION.

Mr. S. A. MAIN (Sheffield) thought the author's work could be regarded as very systematic and carefully carried out, and the data could be accepted. The only observation he would make was that the author attributed an important difference in behaviour under heat treatment and magnetic tests to a very slender percentage of silicon—that is, the difference between about 0.25 and 0.13 per cent. While the conditions of heat treatment under which the “spoiling” of magnet steel occurred were now generally understood, positive evidence of the influence of particular elements in improving, or otherwise, that propensity had so far rather baffled investigation. By positive evidence he meant the kind which could be acted upon with certainty in practice. If, therefore, the author had established a definite effect of silicon in that connection, the knowledge would be highly useful. While personally prepared to find that that small amount of silicon was the real explanation of the interesting facts recorded, before doing so he would like to be assured that the presence of any other disturbing element in appreciable quantity had been carefully looked for.

It was not stated whether the analyses given had been taken on the original ingots, but, if so, it might be desirable to analyse the actual test specimens. On occasions, in work of that kind, the analyses so obtained did not always agree, on fine points, with those obtained from the ingots. In similar cases he, personally, had sometimes found his conclusions as to the influence of small percentages of certain elements on physical properties either negatived or strengthened by such check analyses.

This paper was also presented at the adjourned meeting held in Sheffield on May 10, 1928. The following remarks are extracted from the discussion which took place :

Mr. J. F. KAYSER (Sheffield) said that Mr. Swan's paper was a welcome contribution to magnet steel literature in that it clearly showed the ill-effects of prolonged heat treatments at temperatures of the nature of 800° C. and the necessity for adopting a softening treatment which would not entail a long soaking period. He (Mr. Kayser) was astonished at the high values of BH_{\max} given in the paper. Apparently the author had no difficulty in reaching a value of at least 350,000. From time to time, claims for such high figures were made, but, after many years' experience with tungsten magnet steels from different sources, he (Mr. Kayser) was convinced that such figures could only be obtained under laboratory conditions,

and that a $BH_{\max.}$ of 280,000 was a high average figure for a good tungsten magnet steel. Some of the results given were rather unexpected, and it was unfortunate that the saturation value was not also quoted along with the values for remanence, coercive force, and $BH_{\max.}$ Tests *V7* and *V8* in Table II. were cases in point. The remanence in both cases was essentially the same, but the difference in coercive force amounted to 12, and, strange to say, the magnet with the lower coercive force gave the higher $BH_{\max.}$ Tests *VS4* and *VS1* in Table III. were also peculiar. In that instance, test *VS1* showed slightly higher values for both remanence and coercive force, but the $BH_{\max.}$ was considerably lower than in the case of test *VS4*. He (Mr. Kayser) was, of course, well aware of the fact that it was possible to obtain magnets giving equal values for remanence and coercive force, but showing different values for $BH_{\max.}$ In the cases mentioned, however, he did think that the testing was in some way at fault, and he suggested that in all cases the $BH_{\max.}$ figures quoted were too high. That particularly appeared to be the case in test *VS10*, in which a magnet giving a remanence of 11,000 and a coercive force of only 50 showed a $BH_{\max.}$ of 304,000.

Destructive criticism was frequently alleged to be useless, but in that case he (Mr. Kayser) thought it was necessary, as otherwise an erroneous explanation of the spoiling of magnet steel might be accepted in some quarters, and considerably retard an advance in the knowledge of the subject. Prolonged soaking temperatures slightly above the main critical points seriously impaired the potential magnetic properties of all types of steels, including carbon steels, chromium steels, molybdenum steels, and cobalt steels of various compositions. If it were assumed that the formation of tungsten carbide was responsible for the spoiling of tungsten magnet steel, the spoiling of other steels must be explained by the formation of a somewhat analogous compound. If the author's explanation were correct, it would apparently follow that if, as he stated, the formation of tungsten carbide led to the loss of a certain amount of available carbon and tungsten in the steel, a slight increase in the percentages of those elements would produce a non-spoiling steel. It was, however, well known that, whatever the composition, spoiling did take place if the necessary conditions to produce it occurred. Even if Mr. Swan could definitely show that the crystals shown in his photographs were tungsten carbide, it did not follow that the separation of tungsten carbide caused spoiling. In fact, the evidence was strongly against it.

In his conclusions, the author stated that it was necessary for magnet steel manufacturers to use a maximum reheating temperature for rolling of the order of 1200° C. In view of the author's previous remarks, it seemed to him (Mr. Kayser) that the word "minimum" should be substituted for the word "maximum."

Mr. J. WOOLMAN (Sheffield) said that although the phenomenon of spoiling of magnet steels had been known now for some nine years, the cause of that spoiling and the mechanism of the recovery treatment were still not understood. Any work which would throw light on those problems was welcome, and Mr. Swan was to be thanked for his paper, which provided some evidence concerning the phenomenon. Mr. Kayser had suggested that some of the values for $BH_{\max.}$ were rather high. They, at the Brown-Firth Research Laboratories, had approached those high values, but with quenching temperatures different from those employed by Mr. Swan, which they found were not conducive to the best magnetic results. It would be interesting to know what were the $H_{\max.}$ values employed. The answer might explain the somewhat high values of $BH_{\max.}$ quoted. As for the appearance of hard spots on polished sections, the author gave one the impression that in magnet steels with normal silicon the presence of those hard spots was a criterion of spoiled material. That was contrary to their own observations. They had found very good magnet steels showing those hard spots, which were not very much more numerous although perhaps somewhat larger in the same material when spoiled. The development of the hard spots depended on the carbon content. The fact that the hard spots were actually tungsten carbide (WC) had not been conclusively proved, and whilst he (Mr. Woolman) was of the opinion that tungsten carbide was deposited, that did not fully explain the phenomenon of spoiling. Other constituents were undoubtedly present which influenced the phenomenon.

Mr. SWAN wrote, in reply to Mr. Main, that the ingots were analysed and at least one analysis was taken from each bar rolled from the ingot. The analyses were not extended beyond the eight elements mentioned. In view of the small variation in percentage of silicon involved, it probably would be desirable that the observations should be confirmed or disproved by additional independent work.

Two more steels containing 0.4 to 0.5 per cent. silicon had been made since preparing the paper, and they still showed the same phenomenon—*i.e.* there was no appreciable tungsten carbide segregation when the steels were annealed.

Finally, as regards the influence of silicon, an examination of the analyses of some makes of tungsten die steel showed that the silicon averaged about 0.35 per cent., from which it might be presumed that in practice, it had been found that silicon exercised a beneficial effect, as stated in the conclusion of the paper.

In Mr. Kayser's opinion the $BH_{\max.}$ figures quoted were too high and could only be obtained under laboratory conditions; those, of course, were precisely the conditions under which they were obtained. The author quite agreed with Mr. Kayser that a $BH_{\max.}$ of 360,000 to 380,000 could not be regarded as a commercial proposition, and that a figure of 280,000 was a more acceptable value. Much

would depend, of course, on the section of steel being hardened. It was possible to exceed 280,000 with a $\frac{3}{8}$ -in. bar in works practice, but with an increase in the cross-sectional area of the bar the BH_{\max} would fall. Such high BH_{\max} values had been obtained by Parkin,¹ and also, as mentioned in the discussion, by Mr. Woolman. Referring to tests V7 and V8, Table II., if Mr. Kayser saw the curves the reason would be quite obvious to him why V7, although having a coercive force 12 units lower than V8, gave a higher BH_{\max} , by about 20,000. That of V7 was considerably flatter as it left the remanence point than that of V8. Tests V8 and V9 provided a good example of the consistency with which the hardening and magnetic testing were carried out, since V9 was hardened one month later than V8.

In reply to Mr. Kayser's other remarks, present knowledge indicated that spoiling might be due to one or both of two phenomena—namely, spheroidisation and decomposition of carbide. The former might and did occur, either below or slightly above the critical range, in the latter case when the steel was hypereutectoid. That applied more particularly to the chromium and cobalt steels, since their carbon contents ranged about 1 per cent. Evidence has also been published,² showing that in chromium steels the carbides decomposed above the critical range, and liberated some chromium, which went into solid solution in the ferrite, thus producing a lower remanence in the spoiled steel. The solution of chromium carbides in austenite was very sluggish, and it had been shown that even at 900° C. a considerable time was required to obtain a complete solution, so that the chromium steels, and cobalt steels which also contained a considerable amount of chromium, would be expected to be more susceptible to spoiling by spheroidisation of the carbides. Evidence in support of this view was available, and also that tungsten steels were much less affected than the chromium steels by holding at the hardening temperature for considerable periods. In the author's opinion, therefore, the formation of tungsten carbide was responsible for the major part, if not the whole, of the spoiling. It had been demonstrated that the formation of the crystals was coincident with the spoiling effect, and that when, by heating to 1250° C., the crystals disappeared, the magnetic properties were recovered. Surely that was sufficient evidence that the spoiling was due to the production of such crystals. The crystals were not formed by annealing below the Ac point for 100 hrs. at 675° to 700° C., followed by slow cooling over 14 days.

Under a given set of manufacturing conditions the addition of more tungsten and carbon to the steel might be thought to neutralise a certain loss in coercive force, due to the formation of a more or less constant amount of tungsten carbide. Such a condition did not necessarily hold, since if the concentration of tungsten and carbon were increased,

¹ Parkin, *Carnegie Scholarship Memoirs*, 1924, vol. xiii. pp. 1-46.

² Adams and Goeckler, *Transactions of the American Society for Steel Treating*, 1926, vol. x., pp. 173-190.

more tungsten carbide nuclei would be expected to form, and the amount of carbide liberated would be increased. The spoiling, therefore, could not be eliminated by such means.

The author agreed with Mr. Kayser that a minimum rolling temperature of 1200° C. would be more suitable. The maximum necessary was 1250° C., provided excessive scaling could be avoided on bars of small section. The loss in coercive force at 1200° C. was, however, according to Evershed's results, negligible.

The author was obliged to Mr. Woolman for his confirmation of the high BH_{\max} values. The H_{\max} value for the steels *VA* was 730, and that for steels *VS1* and *VS2* was 510. He agreed that a small number of hard nodules were liable to be present in any steel whether spoiled or not, particularly in the higher carbon steels. It required an annealing time of the order of seven hours at 950° C. before the decomposition of the carbide began to be visible under the microscope, so that a steel could quite easily be spoiled and yet show little, if any, visible signs of carbide decomposition. The fact that Hultgren obtained a similar carbide was not absolute proof that the crystals were tungsten carbide, but the evidence was very strongly in favour of that circumstance, even if they did not correspond to a formula WC. It must be granted that they were a tungsten compound. If H_c was a function of dissolved carbon, then a heat treatment that liberated carbides would reduce the value of H_c , which was what occurred. Further, if B_{rem} was a function of the amount of magnetic iron present, then if the amount of such iron remained unaltered when the steel was spoiled, which again was what occurred (see Table II.) the spoiling was not connected with the ferrite.

It would appear to follow, therefore, that the crystals were a tungsten carbide.

ON THE STRUCTURE OF THE IRON-CHROMIUM-CARBON SYSTEM.*

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INTRODUCTION.

ON account of their great technical importance, the structure of the alloys containing iron, chromium, and carbon has been the subject of numerous investigations. So far, however, the methods applied have only led to uncertain results regarding the nature of the carbide phases found. It therefore seemed desirable that new attempts should be undertaken to determine the structure of this system. In the following will be given a report of such an investigation, the main object of which has been to decide which phases are present in the iron-chromium-carbon system, to characterise them, and, especially, to establish under what conditions each of them is present. At the same time some special analyses have been made of the carbides appearing in the alloys belonging to this system which are most important from a technical point of view, namely, ball-bearing steel, stainless steel, and ordinary ferro-chromium. The principal method of investigation has been X-ray analysis.

It is difficult to give a comparative review of the previous investigations carried out in this domain, because the carbides hitherto reported have generally been described as solid solutions of some chromium carbide in iron carbide or *vice versa*, and the opinions held regarding the different kinds of molecules in these substances vary considerably. X-ray analysis has, however, proved that solid solutions met with in alloys cannot usually be looked upon as groupings of molecules of the dissolved body and the solvent, but that they are formed by atomic substitution.⁽¹⁾

X-ray analysis of the iron-chromium-carbon system has proved that it contains no double carbide in the proper sense of the

* Received December 30, 1927.

word—that is, a carbide, the formation of which would necessitate the presence of both iron and chromium atoms.* The only carbides found are either chromium carbides in which some chromium atoms are substituted by iron atoms, or cementite in which some iron atoms are replaced by chromium atoms.

PREPARATION AND ANALYSIS OF THE ALLOYS.

METHODS OF INVESTIGATION.

The iron-chromium alloys were obtained by melting together samples of electrolytic iron and chromium in magnesia crucibles, in a carbon-tube vacuum furnace. As the alloys could not be stirred during melting, they had to be crushed or, if they were soft, sawn up after the first fusion and then remelted to render them homogeneous.

The same procedure and the same pure materials together with Acheson graphite were employed for preparing the most important ternary alloys—that is, those which were to serve as material for the chemical analysis of the carbides. In the following tables, these alloys are indicated by the numbers 36 to 73. The other ternary alloys, Nos. 1 to 35, were obtained by fusing the raw materials in magnesia crucibles in an open carbon-tube furnace. They were made of electrolytic iron, Acheson graphite, and an alumino-thermic chromium containing 1.0 per cent. iron, 0.8 per cent. aluminium, and 0.2 per cent. silicate inclusions.

The chromium and carbon content of the alloys was determined by chemical analysis. For the carbon analysis the finely powdered samples were mixed with an excess of copper oxide and heated in a current of oxygen at 1100° to 1200° C. This procedure gave satisfactory results even with those alloys which were most resistant to oxidation. The filings obtained from the binary iron-chromium alloys were heated to 1000° C. and maintained for some minutes at this temperature in the vacuum furnace. This treatment of recrystallisation was necessary, because otherwise the crystals, when severely deformed by cold-working, gave only wide and diffuse interference lines.⁽²⁾

* A true double carbide (an iron-tungsten carbide) has been met with in the iron-tungsten-carbon system. It is found in high-speed steel.⁽²²⁾

In order to isolate the carbides, some alloys were treated with dilute hydrochloric acid. X-ray analysis as well as a chemical analysis of the carbide suspension thus formed was then made. When the metallic phase contained austenite the carbide suspension also held a certain quantity of carbon which had been present in the metallic phase. The alloys consisting mainly of carbide phases were crushed, powdered, and recrystallised in a vacuum furnace. Most of the alloys which solidified as austenite were annealed in a vacuum furnace; they were heated to 1000°C . and subsequently cooled at a rate of 0.5° to 1°C . per minute, the dissolved carbon being thus precipitated as carbide. Pieces of certain alloys were ground so as to obtain cylindrical surfaces suited to the cameras, so that the alloys could be examined also in their original state.

The apparatus used for these determinations has been described in earlier publications on this subject.⁽³⁾ The only method of X-ray analysis applied in these investigations was the powder method. The photograms were obtained by means of three cameras, constructed on the focusing principle. For all the exposures a chromium anti-cathode was used.

THE IRON-CHROMIUM SYSTEM.

According to Treitschke and Tammann,⁽⁴⁾ the iron-chromium alloys form a continuous series of solid solutions. Thermic and microscopical analyses led Jänecke⁽⁵⁾ to believe that the series of solid solutions was not unbroken and that a eutectic occurred at about 75 per cent. chromium. This opinion has, however, later been contradicted by Pakulla,⁽⁷⁾ Murakami,⁽⁶⁾ and von Vegesack.⁽⁸⁾ As α -iron and chromium have the same type of lattice, with almost identical dimensions, it seems likely that the first opinion may be correct. This is also confirmed by X-ray analysis (Table I. and Fig. 6). The lattice dimensions vary continuously with the composition.

As, however, chromium only crystallises in one single type of lattice, it follows that the γ range should be limited to the alloys rich in iron. Bain⁽⁹⁾ has found that in alloys containing more than 15 per cent. chromium the γ phase is not present at any temperature (provided the alloys are free from carbon).

δ -iron as well as α -iron crystallises in a body-centred cubic lattice, and as it has been established that the γ - δ transformation is only a reversion of the α - γ transformation, it is evident that iron exists in only two modifications.⁽¹⁰⁾ On the basis of this fact Oberhoffer⁽¹¹⁾ has explained certain observations concerning the recrystallisation of the iron-silicon alloys, by assuming that A_3 and A_4 should approach one another with increasing percentages of silicon, to coincide at about 2.5 per cent. silicon. Above this limit the α and δ ranges form one common domain. X-ray analysis has confirmed Oberhoffer's hypothesis.⁽¹²⁾

Bain holds that the iron-chromium system is analogous in this respect to the iron-silicon system, and in spite of the absence of definite proofs for this supposition, it must be considered to be very probably true.

TABLE I.—*Lattice Dimensions of Iron-Chromium Alloys.*

Chromium. %	Dimension a_1 . Å.
Nil	2.861
8.3	2.863
19.3	2.866
32.1	2.868
51.6	2.871
72.2	2.874
80.3	2.876
100.0	2.878

THE CHROMIUM-CARBON SYSTEM.

An analysis of the chromium-carbon system, reported elsewhere,⁽¹³⁾ has proved that the system contains three different carbides. This analysis has confirmed the statements of Moissan,⁽¹⁴⁾ and of Ruff and Foehr,⁽¹⁵⁾ that one of them has the formula Cr_3C_2 . This carbide crystallises in the orthorhombic system, and its elementary parallelopiped, which contains 20 atoms, has the dimensions $a_1 = 2.821$ Å., $a_2 = 5.52$ Å., and $a_3 = 11.46$ Å. Another carbide—denoted as Cr_5C_2 by Ruff and Foehr—appeared at first to be hexagonal; a closer inspection of its Laue photogram,

as well as an analysis of an analogous manganese carbide, showed, however, that it is trigonal. Its elementary prism probably holds 80 atoms and has the following dimensions: edge of the base $a_1 = 13.98 \text{ \AA}$., height $a_3 = 4.523 \text{ \AA}$. Its formula is thus probably Cr_7C_3 , and not Cr_5C_2 . This carbide is often found in the shape of hexagonal needles in the cavities of chromium-carbon alloys, containing 4 to 9 per cent. carbon. Moissan, who observed these needles earlier than Ruff and Foehr, proposed the formula Cr_4C for them; it was, however, probably based on an analysis of the melt out of which the needles were formed.

A carbide, the composition of which probably corresponds to the formula Cr_4C , does, in fact, exist. It has a face-centred cubic lattice with a parameter of 10.638 \AA . Its elementary cube probably contains 120 atoms. On the solidification of a molten mass, the composition of which corresponds to the formula Cr_4C , primary crystals of the trigonal carbide are obtained, together with secondary crystals of the cubic carbide, enclosed in a eutectic, formed by the cubic carbide and chromium metal. At a sufficiently high rate of cooling, peritectic structures may be obtained even in alloys, the carbon contents of which are 1 to 2 per cent. lower than that corresponding to the formula Cr_4C .

The micrographs Figs. 7 to 9 (Plate XVII.) show that the amount of carbide (carbide white, chromium black) increases with the carbon content. At 6 per cent. carbon the mass becomes apparently homogeneous (Fig. 9). A deeper etching (for instance, with hot 50 per cent. sulphuric acid) shows, however, that the alloy consists of three phases: a strongly etched carbide, a less etched one, and metallic chromium which is rapidly dissolved by the acid (Fig. 10). An alloy containing 4.7 per cent. carbon and another containing 5.3 per cent. carbon and 25 per cent. iron, cooled relatively quickly, present structures of the same kind (Figs. 11 and 12).

Fig. 13 (Plate XVIII.) shows a series of photograms of chromium-carbon alloys. It will be seen how the three series of interference lines, characteristic of each of the three carbides, appear one after the other, as the percentage of carbon increases. Further, it is found that the chromium lines and those of the cubic and trigonal carbides appear together in the photograms of the alloys containing 18 to 21 per cent. of carbon by atomic weight.

THE TERNARY SYSTEM. EQUILIBRIUM DIAGRAM.

The results of chemical analyses, microscopic investigations, and X-ray analyses of the ternary alloys and their carbides are compiled in Tables II., III., and IV. The X-ray examination

TABLE II.—*Alloys containing Cementite.*

Alloy No.	Composition.		Composition of Carbide.			Lattice Dimensions of Carbide.—Å.			Microscopic and other Observations.
	Cr. %	C. %	Cr. %	C. %	Fe. %	a_1 .	a_2 .	a_3 .	
(a) <i>Alloys Cooled in the Furnace.</i>									
34	5.4	2.8	...	...	...	4.51	5.06	6.71	Metallic dendrites + ledeburite
33	5.7	5.5	...	...	...	4.52	5.07	6.73	Cementite + ledeburite
49	9.6	3.7	19.0	...	69.9	4.50	5.07	6.71	Metallic dendrites + ledeburite. Traces of trigonal carbide found by X-ray analysis (see Table III.)
46	9.5	4.5	15.1	...	77.2	4.50	5.06	6.72	Needles of trigonal carbide + ledeburite (Fig. 24, Plate XXII.)
30	9.6	5.8	...	...	...	4.50	5.06	6.72	
17	13.7	7.3	...	...	...	4.51	5.06	6.72	
(b) <i>Annealed Alloys.</i>									
Ball-bearing Steels.	I.	0.00	1.3	...	...	4.517	5.079	6.730	Normal structure Normal structure Banded structure; accumulations of carbide. Micrograph Fig. 27, Plate XXII.
	II.	0.55	1.15	...	...	4.513	5.067	6.721	
	III.	1.67	1.03	9.62	6.83	4.508	5.064	6.713	
		1.86	1.08	...	...	4.515	5.067	6.714	Only the largest carbide grains remain
	III. (quenched)	1.86	1.08	...	...	4.505	5.069	6.722	Ferrite + lamellar pearlite; contains also trigonal carbide
	55	1.97	0.37	...	...	4.514	5.070	6.706	Contains also trigonal carbide
	56	2.46	0.66	...	...	4.513	5.073	6.709	Contains also trigonal carbide
	53	3.09	0.84	...	...	4.51	5.07	6.71	Contains also trigonal carbide
	54	3.98	0.93	...	...	4.5	5.1	6.7	Cementite content very small

makes possible the identification of the phases present in an alloy ; the microstructure shows which phase is first separated. It is thus possible to determine the projection of the liquidus surfaces on the composition plane of a ternary equilibrium diagram. Such a projection is given in Fig. 1.

As mentioned above, only four carbides occur in the iron-chromium-carbon system : cementite, in which a number of iron atoms may be substituted by chromium atoms, and the cubic, trigonal, and orthorhombic chromium carbides, in which the chromium atoms may be substituted by iron atoms.

TABLE III.—*Alloys containing Trigonal Carbide.*

Alloy No.	Composition.		Composition of Carbide.		Lattice Dimensions.—Å.		Microscopic and other Observations.
	Cr. %	C. %	Cr. %	C. %	a_1 .	a_2 .	
(a) <i>Alloys Cooled in the Furnace.</i>							
49	9.6	3.7	...	...	13.9	4.49	A few metallic dendrites in ledeburite
30	9.6	5.8	...	...	13.9	4.49	Carbide phase mainly cementite
17	13.7	7.3	...	...	13.9	4.49	Needles of trigonal carbide in ledeburite;
10	13.0	3.8	31.0	...	13.86	4.489	micrograph Fig. 24, Plate XXII.
31	9.7	2.4	...	...	13.85	4.485	Contains also cementite
51	12.5	2.8	40.9	10.2	13.87	4.491	Eutectic
27	14.4	3.4	44.7	10.2	13.88	4.490	{ Dendrites of austenite + carbide, bordered by a constituent resembling troostite; micrographs Figs. 18 and 19, Plate XXI.
25	28.5	6.6	...	...	13.86	4.489	
15	35.6	8.6	...	...	13.9	4.49	Photogram Fig. 14, V., Plate XIX.
26	14.8	1.7	...	...	13.90	4.495	
24	24.3	3.6	...	...	13.90	4.496	{ Austenite + carbide, bordered by troos- tite; $a_\gamma = 3.620$ Å.; $a_\alpha = 2.877$ Å.
45	23.0	3.2	54.3	10.3	13.90	4.491	
50	23.9	3.0	57.3	9.5	13.91	4.495	{ Needles of trigonal carbide in eutectic of trigonal carbide and austenite; micro- graphs Figs. 20 and 21, Plate XXI.
18	49.6	9.0	...	...	13.96	4.506	
23	27.0	2.0	...	...	13.93	4.505	Very nearly eutectic
58	28.9	2.4	70.4	9.3	13.94	4.505	Dendrites of austenite + carbide, bor- dered by troostite; micrograph
57	28.4	2.0	69.2	9.2	...	...	Fig. 22, Plate XXII.
66	32.1	3.3	...	...	...	...	Very nearly eutectic
69	34.2	2.0	...	...	13.94	4.505	Dendrites of austenite + carbide, bor- dered by troostite
21	49.0	4.0	...	...	13.95	4.51	Needles of trigonal carbide found in a pipe
70	40.5	2.4	...	...	13.94	4.507	Micrograph Fig. 26, Plate XXII.
14	71.4	9.0	...	...	13.96	4.506	
5	69.8	4.0	...	...	13.96	4.515	Eutectic. Contains also cubic carbide
29	77.1	11.1	...	...	13.96	4.513	
Chromium carbide	...	...	...	...	13.98	4.522	Photogram Fig. 14, VII., Plate XIX.
Ferro-chromium I.	69.5	5.0	...	...	13.96	4.517	Brittle. Photogram Fig. 14, IV., Plate XIX.
Ferro-chromium II.	53.3	5.2	...	...	13.96	4.515	Tough
Chromium-nickel steel	11.3	2.4	53.7	8.8	13.86	4.489	1.18 per cent. nickel. Photogram Fig. 14, VI, Plate XIX.
62	27.7	0.48	...	...	...	...	Metallic dendrites with carbide solidified in the grain boundaries. Contains no γ phase
(b) <i>Annealed Alloys.</i>							
55	1.97	0.37	...	...	13.87	4.490	Ferrite + lamellar pearlite; carbide phase mainly cementite; photogram Fig. 15, VII., Plate XX.
56	2.46	0.66	...	...	13.87	4.490	Contains also cementite
53	3.09	0.84	...	...	13.86	4.489	
54	3.98	0.93	...	...	13.87	4.490	
35	5.8	0.63	...	...	13.90	4.492	Contains also cementite; photogram Fig. 15, VIII., Plate XX.
52	7.2	0.79	56.8	10.3	13.90	4.49	
32	9.3	0.78	...	...	13.92	4.491	
							Photogram Fig. 15, IX., Plate XX.

The alloys containing the orthorhombic carbide are relatively troublesome to produce, on account of their high melting point. Their brittleness also renders the microscopic investigation of their structure very difficult, so that no attempts have been made

TABLE IV.—*Alloys containing Cubic Carbide.*

Alloy No.	Composition.		Composition of the Carbide.		Lattice Dimensions. —Å.	Microscopic Observations.
	Cr. %	C. %	Cr. %	C. %		
(a) Alloys cooled in the Furnace.						
70	40.3	2.4	...	...	10.58	Eutectic
72	41.7	2.1	69.4	5.7	10.579	Eutectic
73	45.7	2.0	72.4	6.5	10.585	Metallic dendrites + eutectic
20	47.5	1.9	...	...	10.59	Metallic dendrites + eutectic.
21	49.0	4.0	...	...	10.60	Micrograph Fig. 25, Plate XXII. Needles of trigonal carbide in eutectic of cubic carbide and metal; micrograph Fig. 26, Plate XXII.
9	73.6	2.7	...	...	10.61	Cubic carbide + eutectic
Chromium carbide	...	...	...	...	10.638	Photogram Fig. 14, I., Plate XIX.
Ferro-chromium I.	69.5	5.0	...	...	10.61	See Table III.; photogram Fig. 14, IV., Plate XIX.
Ferro-chromium II.	53.3	5.2	...	...	10.59	See Table III.
(b) Annealed Alloys.						
23	27.0	2.0	...	...	10.567	Micrograph Fig. 23, Plate XXII.
Stainless steel	I. 13.2	0.37	...	...	10.565	Photogram Fig. 14, III., Plate XIX.
	II. 12.7	0.24	54.6	5.0	...	
	III. 12.7	0.32	54.6	5.0	...	

to indicate the liquidus surface of the orthorhombic carbide. The same applies to the liquidus surface of graphite. Probably, however, the solubility of carbon increases with the chromium content of the melt. This fact will be dealt with later in conjunction with the question of the stability of cementite.

The three carbides which may exist in equilibrium with the metallic phases resist fairly well the attack of dilute hydrochloric acid, and may consequently be easily isolated. If the composition of the alloy corresponds to a point on the carbide-metal eutectic line, the solid phases are formed simultaneously. It may be supposed that under those conditions the solid phases are in equilibrium at the solidification temperature, while the composition of the liquid phase that would be in equilibrium with the solid phases does not correspond with that of the alloy. A slight

undercooling of the liquid would suffice to prevent segregation. The composition of the metal phase is given by a point situated

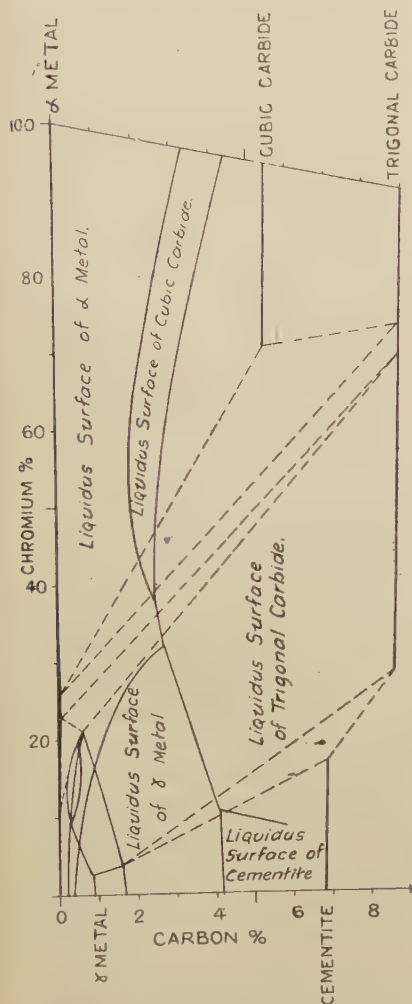


FIG. 1.—Projection of the Three-Dimensional Equilibrium Diagram on the Composition Plane.

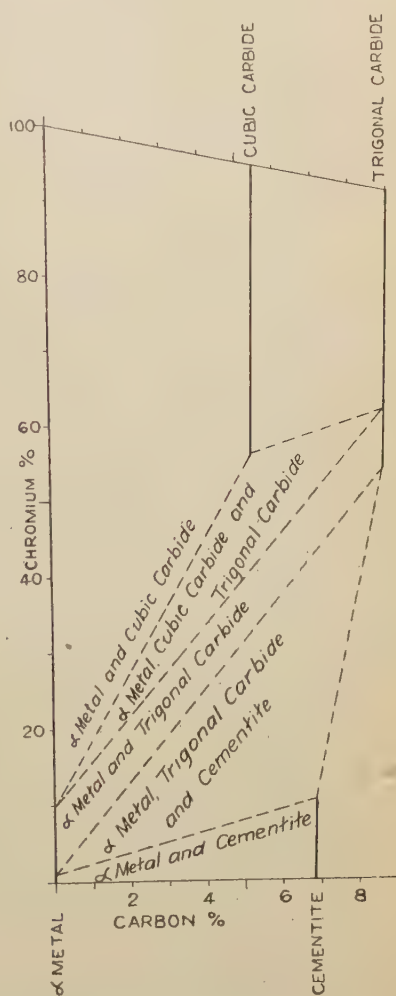


FIG. 2.—Equilibrium at 700° C.

on the prolongation of a straight line connecting the points corresponding to the composition of the alloy and that of the carbide.

There are reasons for presuming that the α phase can dissolve only a slight amount of carbon. No attempts have been made to determine the solubility of carbon in the γ phase.

In the diagram the triangles are indicated in which the alloy, immediately after complete solidification, consists of three phases, the compositions of which are given by the corners of the triangles. It must be observed, however, that these triangles are only schematic. This applies especially to the point which represents austenite with a maximum content of chromium.

Von Vegesack's thermal analysis⁽⁸⁾ makes it probable that along the trigonal-carbide/ γ -metal and trigonal-carbide/ α -metal eutectic lines the temperature rises continuously with an increasing percentage of chromium. This signifies that the points representing the liquid in equilibrium with cubic carbide, trigonal carbide, and α metal, or with trigonal-carbide, α metal, and γ metal, are both situated outside the respective triangles, as indicated by Fig. 1.

According to von Vegesack, the liquidus surface of cementite sinks with an increasing percentage of chromium. Thus, the intersection point of the liquidus surfaces of cementite, trigonal carbide, and γ metal would form a minimum point in the homogeneity range of the liquid phase. The observed high chromium content of cementite is not contradictory to this observation. It seems not impossible that this liquidus point should be situated inside the triangle defined by the corresponding solidus points.

Everything seems to indicate that at a fairly low chromium content cementite is already stable towards graphite. Consequently, the liquidus surface of cementite should intersect that of graphite. If the liquidus surface of cementite sinks with an increasing percentage of chromium, then that of graphite must necessarily decline still more quickly. This fact might be taken as an indication of the presence of chromium carbide molecules in the liquid phase.

All the three carbides may separate also from austenite on annealing. Thus, the homogeneity range of austenite is limited by four surfaces, three corresponding to carbides, and one corresponding to the α phase. Bain⁽⁹⁾ and Kalling and Pagels⁽¹⁶⁾ have shown that the stability of austenite towards the α phase rises with the carbon content, a fact corroborated by our observations.

It is remarkable that the cubic carbide can be in equilibrium with austenite at these low temperatures.

Fig. 2 shows a schematic tracing of an isotherm at about 700° C. The maximum content of chromium in the cementite and the maximum content of iron in the trigonal carbide are considerably reduced. The chromium content of the metal phase, being in equilibrium with both trigonal and cubic carbide, is reduced to less than half its value at the moment of solidification. The maximum iron content of the cubic carbide seems, however, to have increased. The latter has been determined by some analyses carried out on carbides from stainless steels by B. Kalling.*

In order to give an idea of the three-dimensional diagram, the one-phase domains have been indicated in some plane sections of constant chromium content (Figs. 3, 4, and 5).

Figs. 14 and 15 (Plates XIX. and XX.) represent some X-ray photograms typical of the iron-chromium-carbon alloys. It will be seen, for instance, that the photogram of the carbide isolated from stainless steel (Fig. 14, III.) is analogous to that of the cubic chromium carbide (Fig. 14, I.). In the photogram of ferro-chromium (Fig. 14, IV.) the interference lines of the cubic carbide predominate; some faint lines are, however, also to be found, corresponding to the iron-chromium phase and to the trigonal carbide (Fig. 14, VII.). After deeper etching, the microscope also shows that this alloy does not consist only of cubic carbide together with some metallic phase, but that it also contains a slight quantity of trigonal carbide.

The microscopic investigation and the X-ray analysis of the ferro-chromium samples have shown that ferro-chromium II., in spite of its higher carbon content, holds more metal phase than ferro-chromium I. This circumstance accounts for the latter specimen being more brittle than the former. Very likely, ferro-chromium II. has been cooled somewhat more quickly than ferro-chromium I.

The carbide, separated from an unannealed nickel-chromium steel used for making dies, gave a photogram (Fig. 14, VI.) corresponding to the trigonal chromium carbide (Fig. 14, VII.). A ground surface of an iron-chromium-carbon alloy (No. 32, chromium 9.3, carbon 0.78 per cent.), relatively quickly cooled

* Private communication; see Table IV. (b).

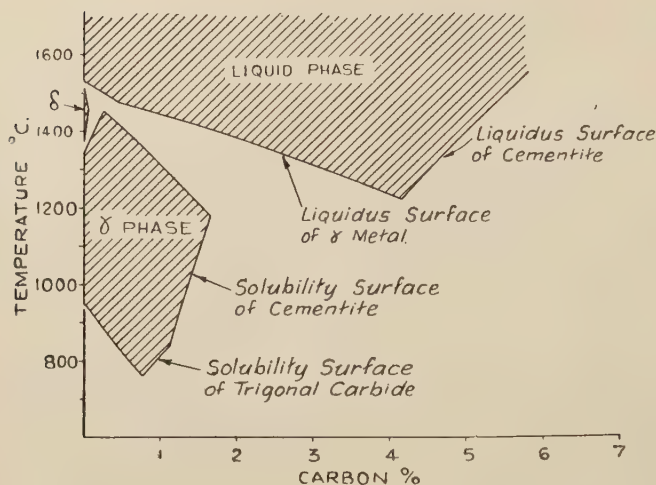


FIG. 3.—Plane Section of the Ternary Diagram corresponding to a Chromium Content of 3%. The Single-Phase Areas are indicated by Hatching.

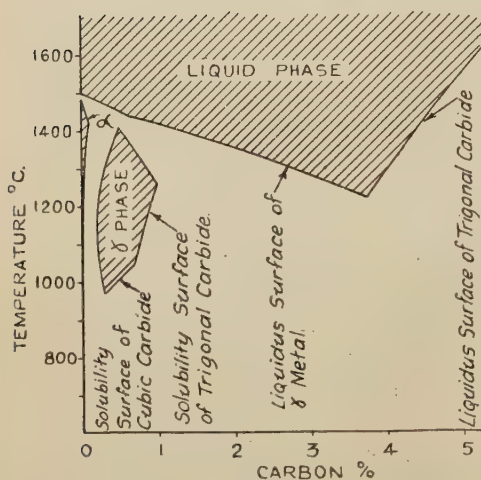


FIG. 4.—Plane Section of the Ternary Diagram at 15% Chromium. The Single-Phase Areas are indicated by Hatching.

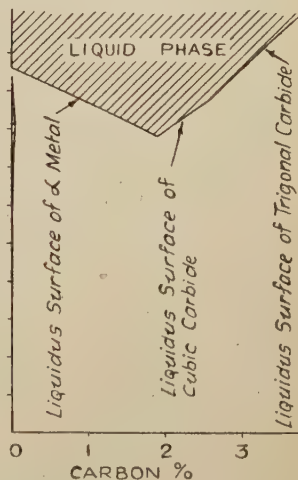


FIG. 5.—Plane Section of the Ternary Diagram at 50% Chromium. The Single-Phase Area is indicated by Hatching.

after melting, gave a photogram (Fig. 14, VIII.) showing only one wide and diffuse line, corresponding to the α metal (troostite), and one weaker, fairly indistinct line, originating from the austenite. The photogram obtained from the same alloy after annealing contained no lines but those corresponding to the α metal (Fig. 14, IX.). The amount of carbide is too insignificant to permit its lines to appear in the photogram of the ground surface. The carbide may, however, be isolated by dissolution of the alloy in a dilute acid, and a photogram (Fig. 15, IX.) is then obtained which clearly shows that it is trigonal.

Some micrographs of a number of typical solidification structures are also reproduced (Figs. 16 to 26, Plates XXI. and XXII.). In some of the alloys containing austenite the carbide grains, formed on solidification, are bordered by a constituent which seems to be troostite. This troostite is less easily etched by hydrochloric acid and sulphuric acid than austenite, but it is rapidly darkened when etched with nitric acid. The same difference in etching effect is found between martensite and austenite.

THE CARBIDES IN BALL-BEARING STEELS.

Fig. 15 (Plate XX.) shows a series of photograms of carbides isolated from alloys relatively poor in chromium and carbon. Fig. 15, I., originates from cementite, isolated from an alloy made up from electrolytic iron and graphite. Fig. 15, II., was obtained from the carbide isolated from ball-bearing steel No. II. From these two patterns it is evident that the latter carbide is nothing but cementite, in which the iron is partly substituted by chromium. This substitution displays itself in the slight displacement of the lines in Fig. 15, II., in relation to the lines of pure cementite. As may be seen, this effect is somewhat less prominent in the photogram of the carbide isolated from steel I. with a somewhat lower chromium content (Fig. 15, III.). From this displacement of the lines it is evident that the lattice dimensions of cementite decrease as the iron atoms are substituted by chromium atoms. The lattice dimensions of pure cementite are $a_1 = 4.517 \text{ \AA.}$; $a_2 = 5.079 \text{ \AA.}$; and $a_3 = 6.730 \text{ \AA.}$ Those of the carbide of steel No. II. are $a_1 = 4.508 \text{ \AA.}$; $a_2 = 5.064 \text{ \AA.}$; and $a_3 = 6.713 \text{ \AA.}$

The variation of the lattice dimensions in this case is, however, of an uncommon kind. Table I. shows that the lattice parameter of the iron-chromium alloys increases with rising chromium content. As shown in Fig. 6, where the dimensions of the cubic and trigonal carbides are recorded graphically, their lattice parameters also grow in size with a rising percentage of

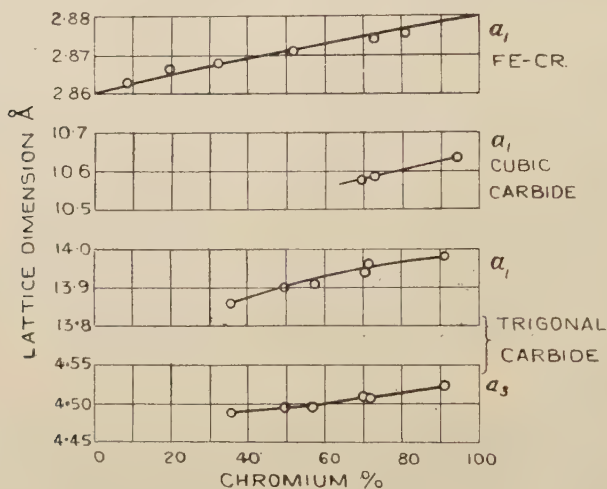


FIG. 6.—Variation of Lattice Dimensions with Chromium Content in Fe-Cr Alloys and Iron-Substituted Chromium Carbides.

chromium. The diminution of the cementite lattice with a rising percentage of chromium is contradictory to the general rule of the variation of lattice dimensions with the composition of solid solutions.*

The analysis of the carbide isolated from steel No. II. gave the value 6.8 per cent. carbon, which agrees well with the formula $(\text{Fe,Cr})_3\text{C}$. Its percentage of chromium was found to be 9.6. If the entire chromium content of the alloy were dissolved in the carbide, then this figure would have been 10.8. Consequently,

* A similar anomaly in the variation of lattice dimensions has been found when iron is substituted by manganese in cementite. Up to about 25 per cent. of manganese by atomic weight the addition of manganese brings about a diminution of the lattice; if the manganese content be further increased, the lattice expands.

in an annealed ball-bearing chromium steel about nine-tenths of the chromium content is contained in the carbide. By studying the electrical conductivity of chromium steels H. Le Chatelier⁽¹⁸⁾ was able to conclude that in annealed steels, relatively low in chromium, almost all the chromium was included in the carbide (compare also Enlund,⁽¹⁹⁾ Edwards and Norbury,⁽²⁰⁾ Portevin and Chevenard⁽²¹⁾).

A special investigation was made on a piece of ball-bearing steel III. which had been rejected on account of its content of so-called "double carbide" or "carbide accumulations." Fig. 27 (Plate XXII.) shows a micrograph of some carbide lines in this steel. Fig. 15, IV. (Plate XX.), shows the photogram obtained from the carbide isolated from this steel in an annealed state. A specimen of this steel was quenched in water from about 1000° C.; it was then examined under the microscope, and it was found that the "normal cementite" (the small carbide grains) was completely dissolved, while the grains of the "double carbide" were still present. These grains were isolated by dissolving the specimen in dilute hydrochloric acid. Fig. 15, V., shows the photogram of the undissolved part. It is exactly similar to Fig. 15, IV. The big carbide grains thus consist of the same phase as the small ones.

At first this result seemed somewhat surprising, as it had been stated to the authors that a chromium steel containing double carbide was etched by hot sodium picrate, the small grains only being coloured, while the big ones remained unaffected. All efforts to etch the steel with hot sodium picrate have, however, given negative results—that is, all the cementite grains, both the small and the large, were unattacked by this reagent. The chromium content of the carbide was probably in this case too high.

The authors, however, later obtained a ball-bearing steel of foreign origin, containing 1.17 per cent. chromium, 1.13 per cent. carbon, and a large amount of "double carbide" which was unetched by hot sodium picrate, while the small grains were strongly coloured. By quenching this specimen from 1000° C., and afterwards dissolving it in hydrochloric acid, the large grains could be separated and examined by X-rays. The photogram obtained was exactly similar to that of the "normal" carbide isolated from the annealed steel, both showing the interferences

of cementite in which the iron was partially substituted by chromium. Thus, also in this case, both the large and small grains of carbide consisted of the same phase.

The fact that only the small grains were affected by etching may possibly be accounted for by some slight difference in chromium content. The photograms of steel No. III. seem to indicate such a difference. The existing data, however, do not allow any definite conclusions in this respect to be drawn, even if the variation in the lattice dimensions exceeds the limit of errors, as the dimensions may be influenced not only by the chromium content, but also by the quenching temperature. The possibility must also be taken into consideration that the carbide may be more easily affected by etching when in a more finely divided state than when present as large grains.

Summing up, it may be concluded that the streaks of so-called "double carbide" which sometimes appear in low-class ball-bearing chromium steels are nothing but unevenly distributed cementite. The fact that the grains of carbide consist of cementite in which the iron has been partially substituted by chromium does not, however, justify their description as "double carbide"; this expression should be reserved for a carbide defined by a structure, the formation of which necessitates the presence of chromium as well as of iron.

Further, it is clear that the formation of these carbide streaks in ball-bearing steels cannot be attributed, as has sometimes been done, to the presence of undissolved carbides, introduced by the ferro-chromium in the bath of the open-hearth furnace. The study of ingots which have given striped steels of this kind after rolling has confirmed this conclusion. From the distribution of the carbide lines in the billets it is evident that they are caused by segregation during the cooling of the ingot. The origin of these carbide lines in the steels in question must consequently be sought amongst the factors which bring about segregation in the ingots.

SUMMARY.

1. X-ray analysis of iron-chromium alloys has proved that these metals form an unbroken series of solid solutions.
2. Microscopic investigations as well as X-ray analyses of

iron-chromium-carbon alloys have proved that in this system the following phases are present :

- (a) α metal.
- (b) γ metal.
- (c) Cementite $(\text{Fe,Cr})_3\text{C}$, in which the amount of chromium may rise to rather more than 15 per cent.
- (d) Cubic chromium carbide—probably $(\text{Cr,Fe})_4\text{C}$ —in which the chromium may be substituted by iron up to about 25 per cent.
- (e) Trigonal chromium carbide $(\text{Cr,Fe})_7\text{C}_3$, in which the iron content may rise to 55 per cent.
- (f) Orthorhombic chromium carbide $(\text{Cr,Fe})_3\text{C}_2$, in which only a few per cent. chromium may be substituted by iron.

On the basis of these data an equilibrium diagram of the iron-chromium-carbon system has been drawn.

3. In an annealed chromium steel of the type used for ball-bearings almost all the chromium is contained in the cementite. The constituent called "double carbide," one of the most common causes for rejection of ball-bearing steels, is not a true double carbide, but only an unequal distribution of cementite, caused by segregation.

4. The carbide in stainless steel is cubic chromium carbide, saturated with iron (about 35 per cent.). A steel containing about 1 per cent. nickel, 11 per cent. chromium, and 2 per cent. carbon (used for dies), contained trigonal chromium carbide, in which rather more than half of the chromium was substituted by iron.

Ferro-chromium with about 60 per cent. chromium and 5 per cent. carbon, used in the production of ball-bearing steel, is a peritectic alloy. It consists principally of the cubic chromium carbide, in which chromium is partially substituted by iron. The rest consists of α metal and some trigonal carbide.

The authors are indebted to the Swedish Ironmasters' Association (Jernkontoret) for financial support for this work. Their thanks are also due to Count B. Kalling, Avesta, for having placed at their disposal ferro-chromium crystals, which were the original starting-point of the investigation.

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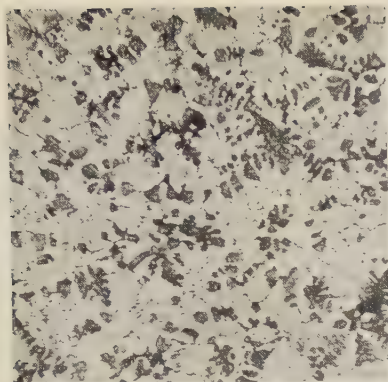


FIG. 7.—Cr-C; 3.3 per cent. C. Etched with HCl. $\times 50$.

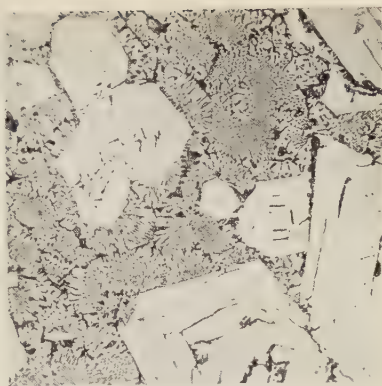


FIG. 8.—Cr-C; 3.6 per cent. C. Etched with HCl. $\times 50$.



FIG. 9.—Cr-C; 6 per cent. C. Etched with HCl. $\times 150$.

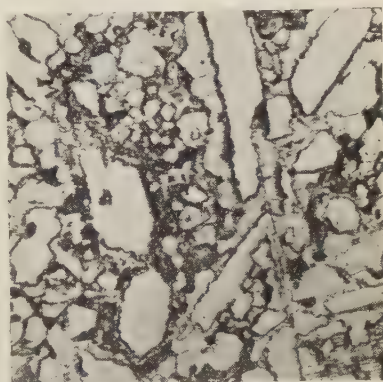


FIG. 10.—Same as Fig. 9. Etched with 50 per cent. H_2SO_4 . $\times 150$.

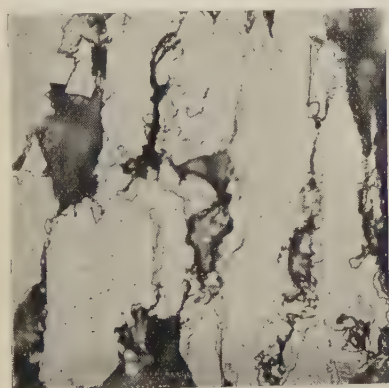


FIG. 11.—Cr-C; 4.7 per cent. C. Etched with 50 per cent. H_2SO_4 . $\times 600$.



FIG. 12.—Fe-Cr-C. No. 5; 69.8 per cent. Cr, 5.3 per cent. C. Etched with 50 per cent. H_2SO_4 . $\times 600$.

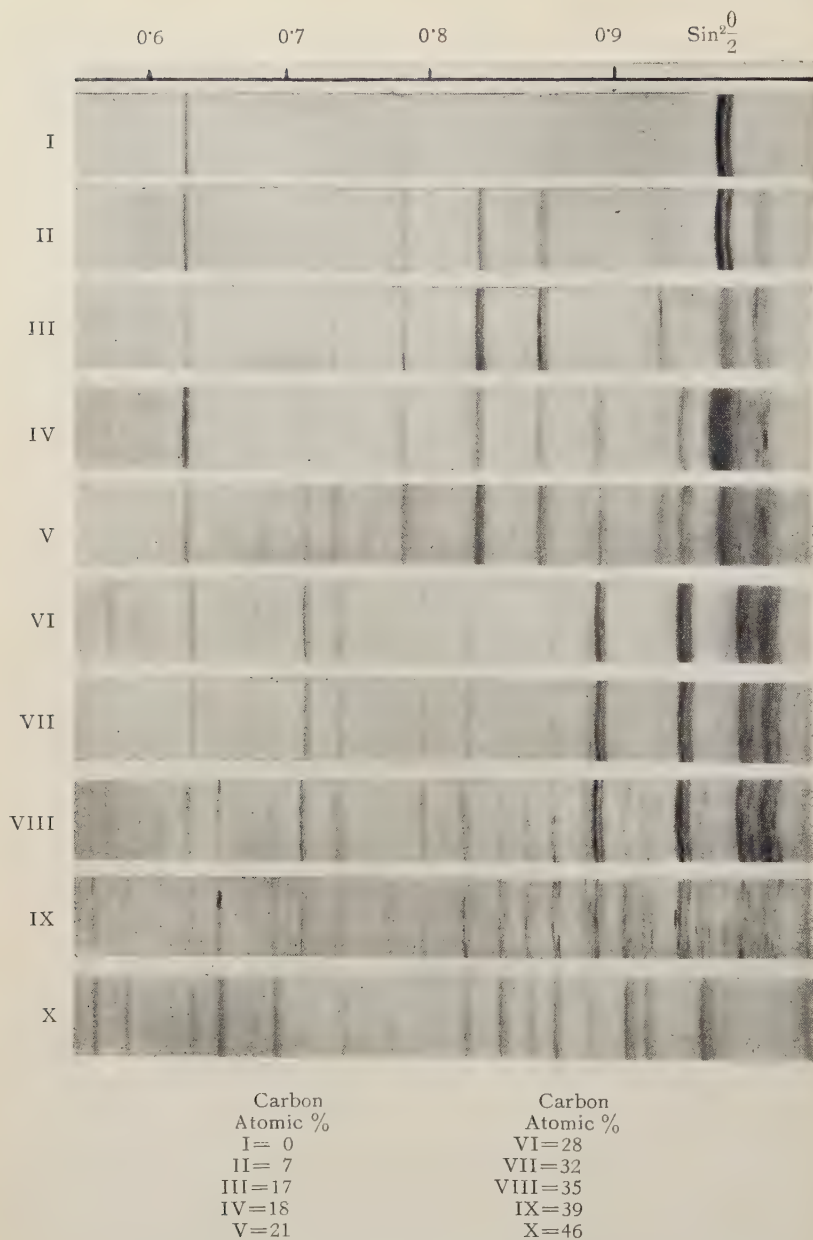
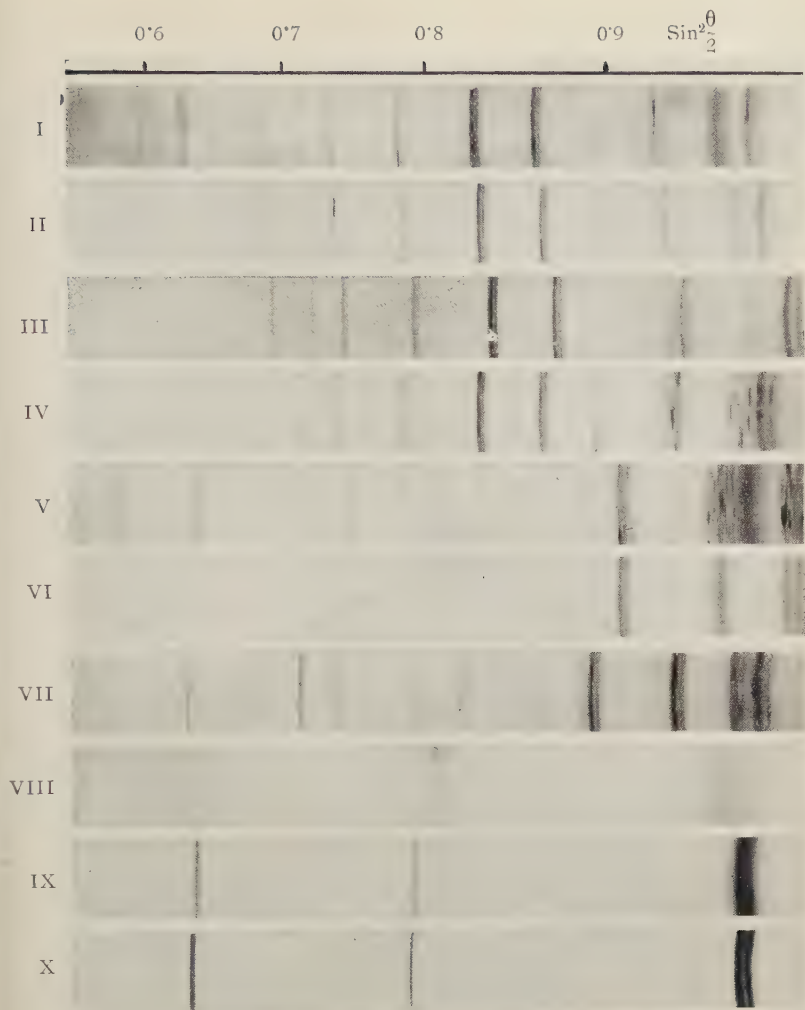


FIG. 13.—Powder photographs of chromium-carbon alloys. Cr-K radiation.
IV, Comparatively rapidly cooled.



- I. Cubic chromium carbide+chromium.
- II. Cubic crystals formed in ferro-chromium.
- III. Carbide, isolated from stainless steel (13.2 per cent. Cr, 0.37 per cent. C).
- IV. Ferro-chromium I (69.5 per cent. Cr, 5 per cent. C).
- V. Fe-Cr-C alloy No. 25 (28.5 per cent. Cr, 6.6 per cent. C).
- VI. Carbide, isolated from a Cr-Ni steel (11.33 per cent. Cr, 1.18 per cent. Ni, 2.38 per cent. C).
- VII. Trigonal chromium carbide.
- VIII. Fe-Cr-C alloy No. 32 (9.3 per cent. Cr, 0.78 per cent. C); unannealed; ground surface.
- IX. Fe-Cr-C alloy No. 32; annealed; ground surface.
- X. Fe-Cr alloy (8.3 per cent. Cr).

FIG. 14.—Powder photograms of Fe-Cr-C alloys and of isolated carbides. Cr-K radiation.



Composition of Steels.

Chromium %	Carbon %		Chromium %	Carbon %
I=0	1.3 (approx.)		VI=5.4	2.8
II=1.67	1.03		VII=1.97	0.37
III=0.55	1.15		VIII=3.98	0.93
IV=1.86	1.08		IX=9.3	0.78
V=1.86	1.08	Quenched from 1000° C.	X=Trigonal chromium carbide.	

FIG. 15.—Powder photograms of cementite and of carbides, isolated from chromium steels. Cr-K radiation.

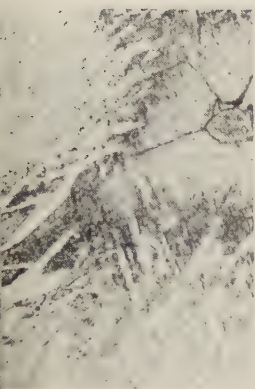


FIG. 16.—Alloy No. 32, 9.3 per cent. Cr, 0.78 per cent. C, cooled in the furnace. Metallic dendrites with martensite (in high relief) in the inner and austenite (strongly etched) in the outer parts. Etched with H_2SO_4 . $\times 900$.



FIG. 17.—Same as Fig. 16, etched with HNO_3 . Austenite smooth after etching; martensite attacked. $\times 900$.

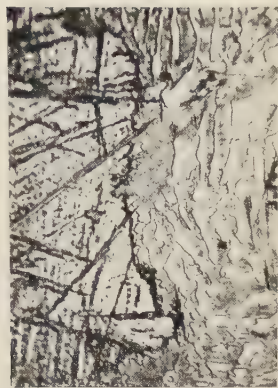


FIG. 18.—Alloy No. 31, 9.7 per cent. Cr, 2.4 per cent. C, cooled in the furnace. Austenitic dendrites with lamellae of martensite, surrounded by trigonal carbide in troostite. Etched with H_2SO_4 . Austenite more affected by etching than troostite and martensite. Structure shows that the martensite is formed earlier than the troostite. $\times 900$.

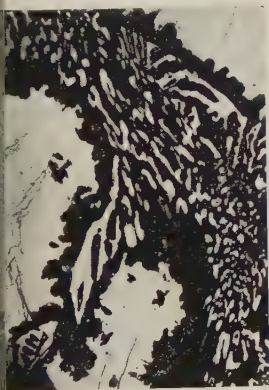


FIG. 19.—Same as Fig. 18, etched with HNO_3 . Austenite smooth; troostite darkened. $\times 900$.

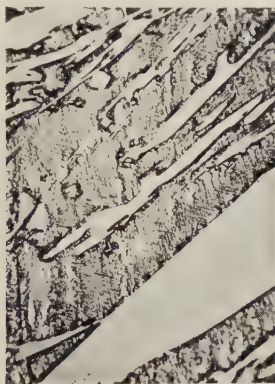


FIG. 20.—Alloy No. 24, 24.3 per cent. Cr, 3.6 per cent. C, cooled in the furnace. Needles of trigonal carbide in eutectic of trigonal carbide and austenite. Etched with H_2SO_4 . $\times 900$.

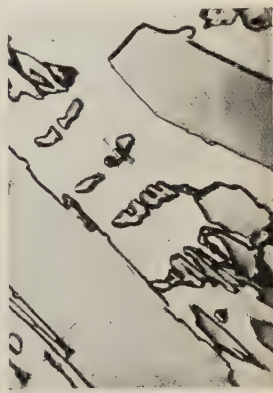


FIG. 21.—Same as Fig. 20, etched with HNO_3 . Only boundaries between austenite and carbide attacked. Austenite lighter than carbide. $\times 900$.

(The above micrographs have been reduced to eight-elevenths in reproduction.)

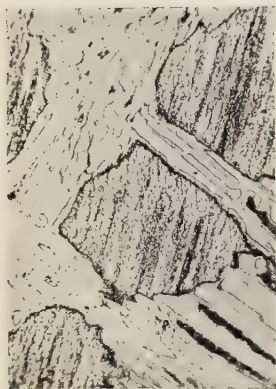


FIG. 22.—Alloy No. 23, 27 per cent. Cr, 2 per cent. C, cooled in the furnace. Austenite dendrites (strongly etched), surrounded by trigonal carbide in troostite. Etched with H_2SO_4 . $\times 900$.

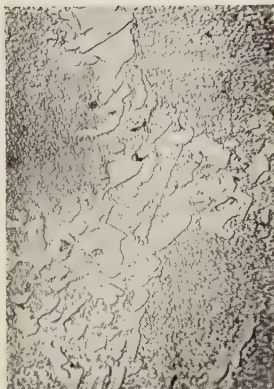


FIG. 23.—Same as Fig. 22, annealed. Austenite and troostite decomposed, forming α -metal and cubic carbide. Etched with HCl. $\times 900$.



FIG. 24.—Alloy No. 30, 9.6 per cent. Cr, 5.8 per cent. C. Etched with $K_2Fe(CN)_6 + KOH$ according to Murakami. Needle of trigonal carbide (blackened), cementite lamellae (light grey) and ledeburite. $\times 200$.

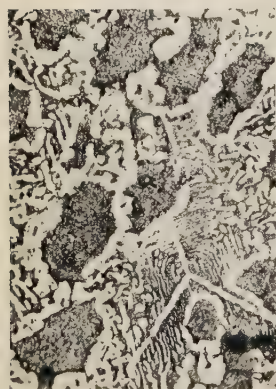


FIG. 25.—Alloy No. 20, 47.5 per cent. Cr, 1.9 per cent. C. Metallic dendrites and eutectic cubic carbide+metal. Etched with HCl. $\times 400$.

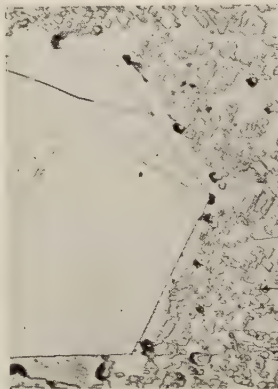


FIG. 26.—Alloy No. 21, 49 per cent. Cr, 4 per cent. C. Section of needle of trigonal carbide surrounded by eutectic of cubic carbide+metal. Etched with HCl. $\times 400$.

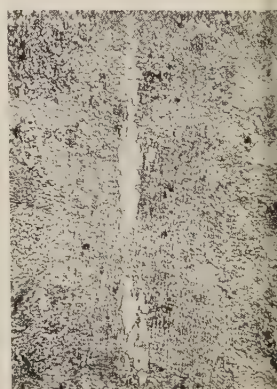


FIG. 27.—Streak of carbide in ball-bearing steel III with 1.1 per cent. Cr and 1.08 per cent. C. Etched with alcoholic HNO_3 . $\times 400$.

(The above micrographs have been reduced to eight-elevenths in reproduction.)

SECOND REPORT ON THE HETEROGENEITY OF STEEL INGOTS.

BY A COMMITTEE OF THE IRON AND STEEL INSTITUTE.

SUBSEQUENT to the presentation of the First Report (May, 1926), the Committee on Heterogeneity of Steel Ingots has been enlarged by the co-option of several gentlemen, able to assist materially in the continued investigations, and the Committee is now constituted as follows :

Professor J. H. ANDREW (Royal Technical College, Glasgow).
 Mr. G. W. AUSTIN (R.N. Torpedo Factory, Greenock).
 Professor H. C. H. CARPENTER, F.R.S. (Royal School of Mines, London).
 Mr. T. P. COLCLOUGH (The Park Gate Iron and Steel Co., Ltd.).
 Mr. W. J. DAWSON (Messrs. Hadfields, Ltd.).
 Professor C. H. DESCH, F.R.S. (The University, Sheffield).
 Mr. J. H. S. DICKENSON (Messrs. Vickers-Armstrongs, Ltd.)—*Vice-Chairman*.
 Mr. A. P. HAGUE (Messrs. Cammell Laird & Co., Ltd.).
 Dr. W. H. HATFIELD (The Brown-Firth Research Laboratories)—*Chairman*.
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 Dr. H. MOORE, O.B.E. (Research Department, Woolwich).
 Mr. T. M. SERVICE (Messrs. Wm. Beardmore & Co., Ltd.).
 Mr. H. SUTTON (Royal Aircraft Establishment, Farnborough).
 Mr. J. H. WHITELEY (The Consett Iron Co., Ltd.).

The Committee is now able to present this, its Second Report. The work is confined to a consideration of further types of carbon steel ingots, and to several examples of alloy steel ingots. Consideration is also given to the subject of ingot moulds. Scientific investigations are in hand with a view to the elucidation of matters arising out of the first general research. The whole of the work has been made possible through the generosity of the firms with which some of the members are associated, in supplying data, and in facilitating and financing a most costly form of investigation, whilst for the last-mentioned investigations the Iron and Steel Institute is providing the necessary funds.

The Report is divided into the following sections :

SECTION I.—Introduction.

SECTION II.—Ingot moulds.

SECTION III.—Certain features of steel manufacture which may influence heterogeneity.

SECTION IV.—A study of nickel, nickel-chromium, and nickel-chromium-molybdenum steel ingots.

SECTION V.—A study of carbon steels other than “killed.”

SECTION VI.—An interim report on the researches at Sheffield University and Glasgow Royal Technical College.

SECTION VII.—Bibliography (brought up to date).

SECTION I.—*Introduction.*

The First Report, issued by the Committee in May, 1926, dealt with carbon steel ingots of various sizes, the steel having been so refined that gases given off during the freezing of the ingot did not produce blowholes—*i.e.* all the steel was of the “killed” type, and, consequently, the ingots were of the sound type. The researches of the Committee showed, however, that all the ingots, although representing good normal production, disclosed definite heterogeneity as regards the distribution of the carbon, sulphur, and phosphorus, and, further, that the degree of heterogeneity increased with increase in the mass of the ingot. It was suggested that these variations in composition were due to the manner in which the liquid steel solidified, and whilst Section IV. of the First Report was devoted to a consideration of the influence of the various factors involved, and to a tentative discussion of certain theories in explanation of the observed facts, it was realised that much research was necessary before any attempt could be made to give a complete picture of the mechanism of freezing. In certain directions the Committee has since been able to provide for the execution of several much-needed investigations. Until this work is more advanced the Committee proposes to abstain from a further theoretical dissertation upon the results, and this Second Report will be confined, as far as possible, to a statement of the essential facts determined. Where explanations of isolated phenomena are discussed, the object is simply to

encourage useful discussion. As indicative of the difficulties of arriving at a complete understanding of the general problem, attention may be drawn to the experimental difficulty of determining the temperature gradients existing within the steel and the mould during the actual freezing, and, incidentally, to the difficulty of obtaining the necessary data to enable the thickness of the advancing wall of frozen steel to be plotted against time. The study of any movement of the liquid steel in the form of convection currents is also difficult. Such problems are, however, receiving attention.

The design of the mould is of great influence in affecting the characteristic features of the ingot cast in it. In Section II., therefore, particulars of many of the moulds used for producing the ingots studied are presented, and some consideration in detail is given to the manner in which the mould affects the freezing of the ingot. Here, again, is a general problem which does not permit of any attempt at final statement until much more data have been obtained.

The Committee, having now under consideration various types of ingots produced by different processes, has felt it to be desirable that certain metallurgical considerations should be discussed, and Section III. is therefore devoted to that purpose. It is shown how the available resources of raw material influence the character of the process and product, and to what extent technical control is limited by the degree of scientific achievement.

Section IV. contains valuable data derived from the study of further ingots. The First Report dealt with carbon steel ingots produced from fully killed steel, and an account is now given of alloy steel ingots produced from fully killed steel containing nickel, nickel and chromium, and nickel, chromium, and molybdenum; whilst in one case the distribution of a small quantity of copper present in the ingot is studied. These steels, as is generally known, are employed where enhanced mechanical characteristics are necessary to withstand the high stresses to which they are subjected in their final form. Incidentally, the temperatures permissible in the hot-working of such not so readily weldable steels, do not permit of raising them to welding heats, and it is therefore imperative that the ingot material shall be free from cavity of any kind. The ingots studied indicate

that a high technical standard has been attained in the production of such material. A refractory-lined feeder head is invariably used for preventing a shrinkage cavity within the ingot proper, with the further effect, in conjunction with the design of mould, of causing the major segregates to collect in the feeder portion of the ingot, which is discarded. The data presented will enable the degree of segregation of the special elements to be judged, and also, in some measure, their effect as regards the segregation of the normal elements.

In Section V. the Committee presents data derived from several ingots representative of the great tonnages of mild steel produced. Such steel is manufactured in far greater quantity than the solid steel, both carbon and alloy, hitherto considered. Where killed steel is made for the production of forgings and other products from which onerous service is expected, the large discard from the top of the ingots results in a very materially enhanced cost of the product. In the type of material discussed in this section, the yield of finished product is much higher, thus facilitating the economic object in view of providing a large tonnage of cheap material for general purposes. Incidentally, this material is usually fairly low in carbon, and the rolling temperatures are high, and these factors result in a material satisfactory for the purposes intended, since minor cavities may weld up in the manipulative processes. Nevertheless, a comparative study of ingots of such material is essential for a proper comprehension of the whole problem of ingot production. The study of the effect of gases given off during freezing also becomes possible, with very instructive results.

In Section VI. will be found a statement reporting progress of the researches undertaken on behalf of the Committee. At Sheffield University, Professor Desch, F.R.S., has made himself responsible for work upon the viscosity and density of molten steels, whilst at the Glasgow Royal Technical College, Professor Andrew has undertaken a study of the liquidus and solidus of the steels under consideration, together with a study of the formation and nature of the sulphides in commercial steels.

In Section VII. the Committee is able, through the assistance of Mr. Lloyd and his staff, to present a summary of literature published since the bibliography in the last Report was compiled.

Opportunity is here taken of recording the appreciation of the assistance given by various steel-makers, both at home and abroad.

SECTION II.—*Ingot Moulds.*

Of the factors influencing the characteristics of the ingot, the form of mould employed is necessarily one of the most important. It was therefore considered that the presentation of adequate data concerning the design and general details of the moulds used would enhance the value of the results of the researches on the ingots themselves. Particulars are now given of some of the moulds used for the ingots described in the First Report, and for each of these dealt with in the present Report; brief details are given in Table I., and dimensioned drawings are given in Figs. 1 to 18.

It is clear that there should be an optimum design of mould for producing any particular steel ingot, and that the design may be influenced by the type and composition of the steel, and by the use to which the ingot is to be put. The optimum design for a given purpose cannot be definitely determined until the phenomena of freezing are more completely understood. The details here given are instructive, however, as indicative of the present "state of the art," and will perhaps assist in the further development of technique. To state in detail the exact functions of the mould is, in the present state of knowledge, almost as difficult and controversial as to attempt to explain the phenomena of the freezing of the ingot. It should, however, be appreciated that the practical development has attained such a standard that ingots can now be produced which are free from many of the defects that were responsible in early days for certain forms of unreliability. This particularly refers to the position of the shrinkage cavity, and the position of the main segregates in the ingot as cast, both of which are largely determined by the design of the mould and the feeder-head. In the First Report, only "fully killed" or piping steel was considered, but here steel with other characteristics is also dealt with, and in considering the various ingot moulds the type of steel must be kept in mind. Piping steel is necessary for all ingots

TABLE I.—*Mould Details.*

Fig. No.	Symbol.	Ingot.				Mould.									
		Total Weight.		Weight in Chll.		Weight of Feeder.		Shape.	Purpose.	Weight of Chll. Tons cwt. qr. lb.	Ratio of Weight of Chll. to Weight of Steel in Chll. %	Weight of Mould per sq. ft. of Surface at X X. Lb.	Weight of Steel covered by 1 sq. ft. of Mould at X X. Lb.	Ratio of Weight of Mould to Weight of Steel. %	Ingot Example Number.
		Tons cwt. qr. lb.	Tons cwt. qr. lb.	Tons cwt. qr. lb.	Tons cwt. qr. lb.										
1	A	0 15 3 0	0 13 1 5	0 2 1 23	Square	Alloy steel	0 18 0 0	135	178	121	147	17			
2	B	1 3 1 0	1 3 1 0	...	Octagonal	Rly. carbon steel	1 1 3 0	93	111	126	89	32			
3	C	1 15 0 0	1 11 0 0	0 4 0 0	Square	Alloy steel	2 11 0 0	164	308	151	204	...			
4	D	2 4 0 0	1 16 2 0	0 7 2 0	Square	Alloy steel	4 3 0 0	227	286.5	159	180	19 & 20			
5	E	2 16 0 0	2 0 3 0	0 15 1 0	Rectangular	Rly. carbon steel	2 7 3 0	117	223	191	116	4 ¹			
6	F	2 17 0 0	2 7 3 14	0 9 0 14	Square	Alloy steel	4 15 0 7	198	263	197	133	18			
7	G	2 18 2 0	2 11 0 0	0 7 2 0	Rectangular	Plate steel	3 10 0 0	137	218	202	108	5 ¹			
8	H	2 18 0 0	2 11 0 0	0 7 0 0	Twelve-sided	Carbon steel	3 2 0 0	121	194	200	97	6 ¹			
9	I	3 6 0 0	2 16 0 0	0 10 0 0	Square	Billet steel	3 11 0 0	127	204	206	...	29			
10	J	6 15 0 0	6 15 0 0	...	Rectangular	Plate steel	5 3 0 0	76	206	301	68	25 & 27			
11	K	7 15 0 0	7 15 0 0	...	Rectangular	Plate steel	7 11 0 0	97	258	312	82	26			
12	L	7 14 0 0	7 14 0 0	...	Rectangular	Plate steel	7 16 0 0	101	277	287	...	30 & 31			
13	M	8 0 0 0	8 0 0 0	...	Rectangular	Plate steel	...	...	258	303	85	8 ¹ & 28	
14	N	9 7 3 0	8 1 0 0	1 6 3 0	Octagonal	Alloy steel	9 3 0 0	126	392	347	113	...			
15	O	17 12 0 0	15 7 0 0	2 5 0 0	Octagonal	Alloy steel	18 9 0 0	120	377	315	119	11 ¹			
16	P	25 0 0 0	18 15 0 0	6 5 0 0	Octagonal	Alloy steel	17 15 0 0	94	408	414	98	12 ¹			
17	Q	50 3 0 0	40 8 0 0	9 15 0 0	Round	Alloy steel	41 4 0 0	101	...	...	...	22
18	R	119 10 0 0	96 10 0 0	23 0 0 0	Octagonal	Alloy steel	64 2 0 0	66	...	...	...	23

¹ See First Report, *Journal of the Iron and Steel Institute*, 1926, No. I. pp. 48-77.

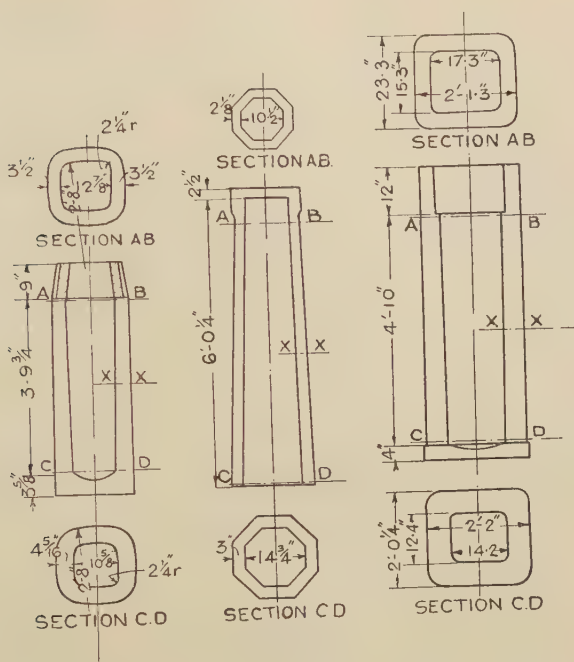


FIG. 1.—Mould A. FIG. 2.—Mould B. FIG. 3.—Mould C.

	Mould A. Lb.	Mould B. Lb.	Mould C. Lb.
Weight of steel covered by 1 sq. ft. of mould at XX	121	126	151
Weight of mould per sq. ft. of surface of ingot at XX	178	111	308
	Sq. in.	Sq. in.	Sq. in.
Sectional area of ingot at AB	151	87	264
" " " " at CD	105	173	168
" " " " mould at AB	195	89	313
" " " " at CD	215	176	448
	Owt. qr. lb.	Ton cwt. qr.	Tons cwt.
Total weight of ingot	15 3 0	1 3 1	1 15
Weight of mould . . . . .	...	1 1 3	...
Weight of chill portion of ingot	13 1 5	...	1 11
" " " " " mould	18 0 0	...	2 11

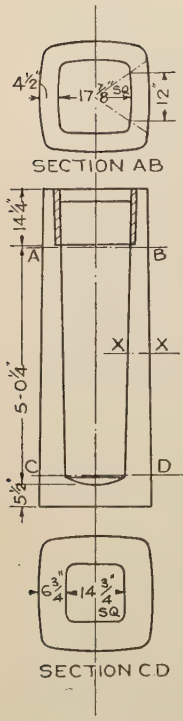


FIG. 4.—Mould D.

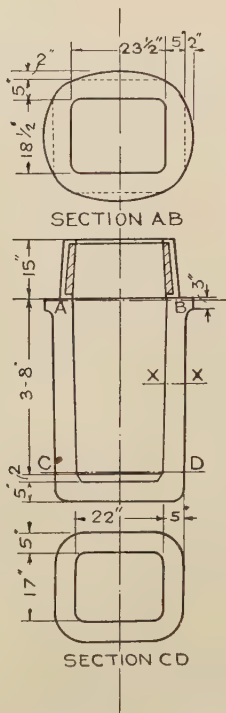


FIG. 5.—Mould E.

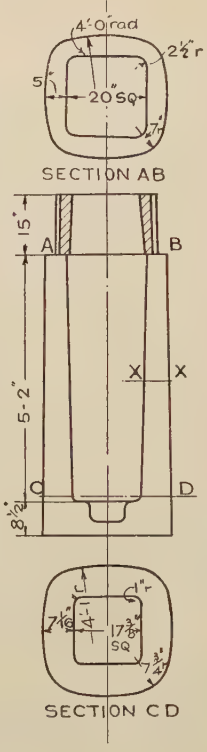
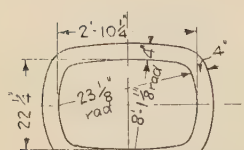
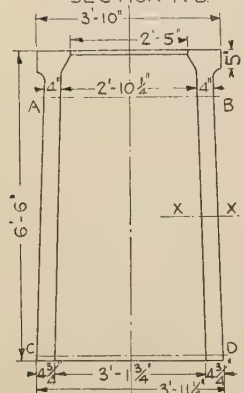


FIG. 6.—Mould F.

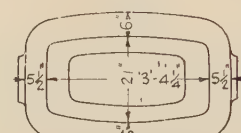
	Mould D. Lb.	Mould E. Lb.	Mould F. Lb.
Weight of steel covered by 1 sq. ft. of mould at XX	159	191	197
Weight of mould per sq. ft. of surface of ingot at XX	286.5	223	263
	Sq. in.	Sq. in.	Sq. in.
Sectional area of ingot at AB	301	427	395
" " " " at CD	192	366	301
" " " " mould at AB	396	590	411
" " " " at CD	557	443	593
	Tons cwt. qr.	Tons cwt. qr.	Tons cwt. qr. lb.
Total weight of ingot	2 4 0	2 16 0	2 17 0 0
Weight of chill portion of ingot	1 16 2	2 0 3	2 7 3 14
" " " " " mould	4 3 0	2 7 3	4 15 0 7



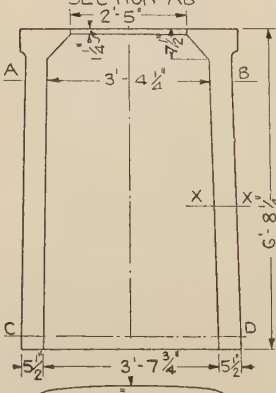
SECTION A.B.



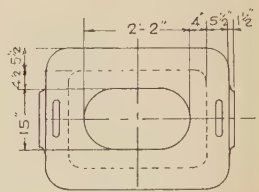
SECTION C.D.



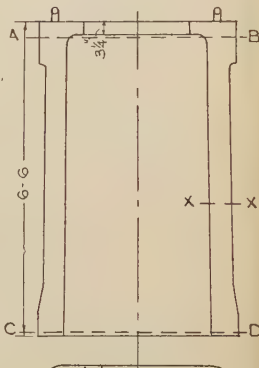
SECTION A.B.



SECTION C.D.



TOP OF MOULD



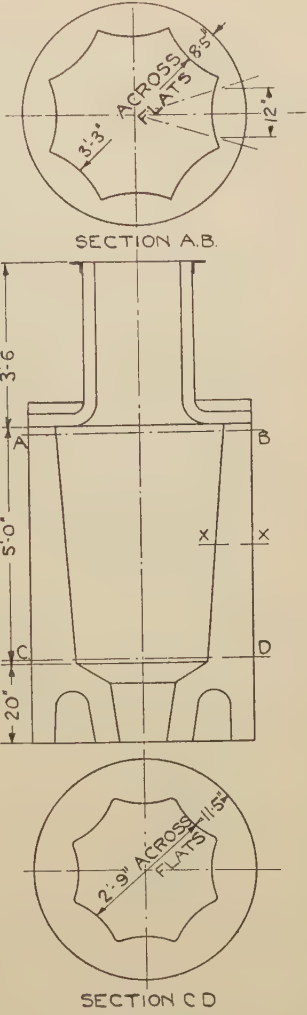
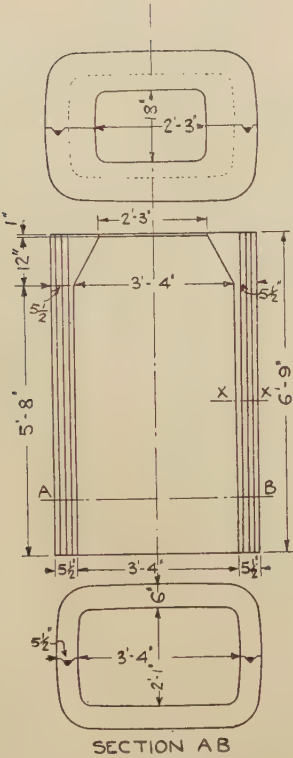
BOTTOM OF MOULD

FIG. 10.—Mould J.

FIG. 11.—Mould K.

FIG. 12.—Mould L.

	Mould J. Lb.	Mould K. Lb.	Mould L. Lb.
Weight of steel covered by 1 sq. ft. of mould at XX	301	312	287
Weight of mould per sq. ft. of surface of ingot at XX	206	258	277
	Sq. in.	Sq. in.	Sq. in.
Sectional area of ingot at AB	688	800	808
„ „ „ at CD	896	1018	924
„ „ „ mould at AB	446	704	731
„ „ „ „ at CD	580	826	945
	Tons cwt.	Tons cwt.	Tons cwt.
Total weight of ingot	6 15	7 15	7 14
Weight of chill portion of ingot	6 15	7 15	7 14
„ „ „ „ „ „ mould	5 3	7 11	7 16



	Mould M. Lb.	Mould N. Lb.
Weight of steel covered by 1 sq. ft. of mould at XX .	303	347
Weight of mould per sq. ft. of surface of ingot at XX .	258	392
Sectional area of ingot at AB	Sq. in. 938	Sq. in. 1296
" " " at CD . . . . .	...	915
" " mould at AB	818	1130
" " " at CD . . . . .	...	1437
Total weight of ingot	Tons. 8	Tons cwt. gr. 9 7 3
Weight of chill portion of ingot . . . . .	...	8 1 0
" " " " " mould . . . . .	...	9 3 0
Percentage weight of head . . . . .	...	20%

which are to be made into forgings and into some other forms, particularly where the steel contains special elements. As defects in the ingot may remain in the finished part, the mould is so designed, and also given a feeder-head, to ensure that the shrinkage cavity and also the bulk of the segregate shall be in the upper portion which is scrapped.

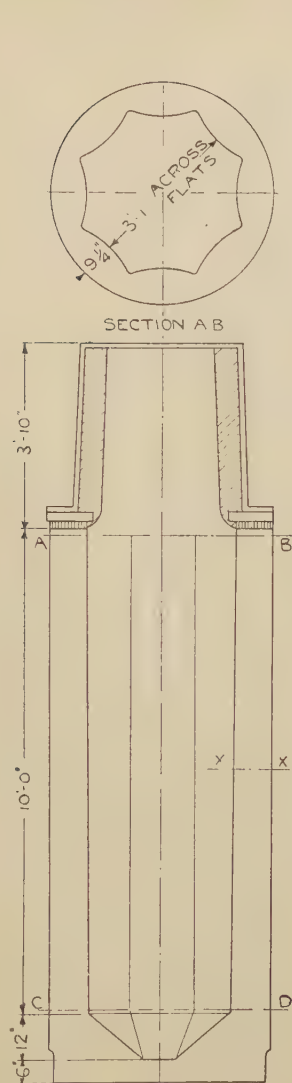
Material of the Moulds.

All the moulds at present under examination by the Committee are made of cast iron, which material meets, to a reasonable degree, the demand as regards physical properties, maintenance, and cheapness. Its low cost, due partly to its ease of manufacture, its comparatively high thermal conductivity, and the fair life of the surface coming repeatedly in contact with the molten steel, coupled with a satisfactory mechanical strength, have proved sufficient justification for the general use of the material. Steel moulds are used to some extent, and it is quite realised that further investigation may indicate possibilities of development, for special cases, in the material of the mould. As indicative of the compositions of cast irons used, the following figures, resulting from the analysis of a large mould which had produced 130 ingots, are instructive :

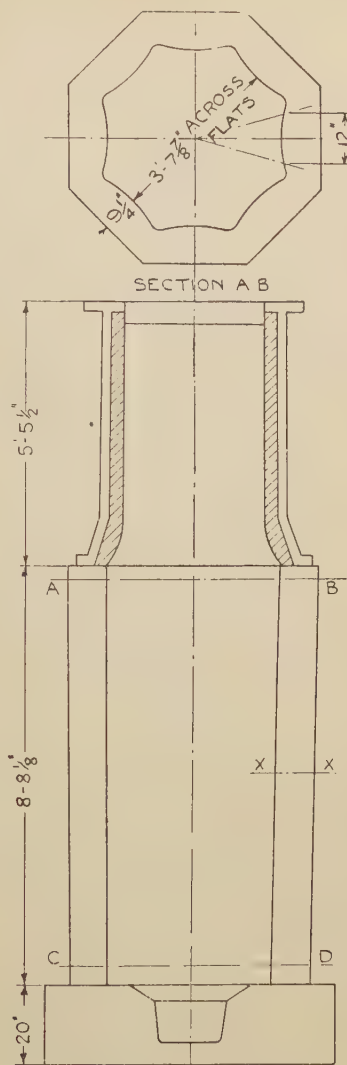
Total carbon	.	.	.	.	.	.	3.70
Graphite	.	.	.	.	.	.	2.91
Manganese	.	.	.	.	.	.	0.42
Silicon	.	.	.	.	.	.	0.98
Sulphur	.	.	.	.	.	.	0.03
Phosphorus	.	.	.	.	.	.	0.026

Details of Moulds O and P (Figs. 15 and 16).

	Mould O. Lb.	Mould P. Lb.
Weight of steel covered by 1 sq. ft. of mould at XX .	315	414
Weight of mould per sq. ft. of surface of ingot at XX .	377	408
	Sq. in.	Sq. in.
Sectional area of ingot at AB	1155	1606
" " " at CD	1033	1383
" " mould at AB	1264	1548
" " " at CD	1386	1481
	Tons cwt.	Tons cwt.
Total weight of ingot	17 12	25 0
Weight of chill portion of ingot	15 7	18 15
" " " " " mould	18 9	17 15



SECTION C D
FIG. 15.—Mould O



SECTION C D
FIG. 16.—Mould P.

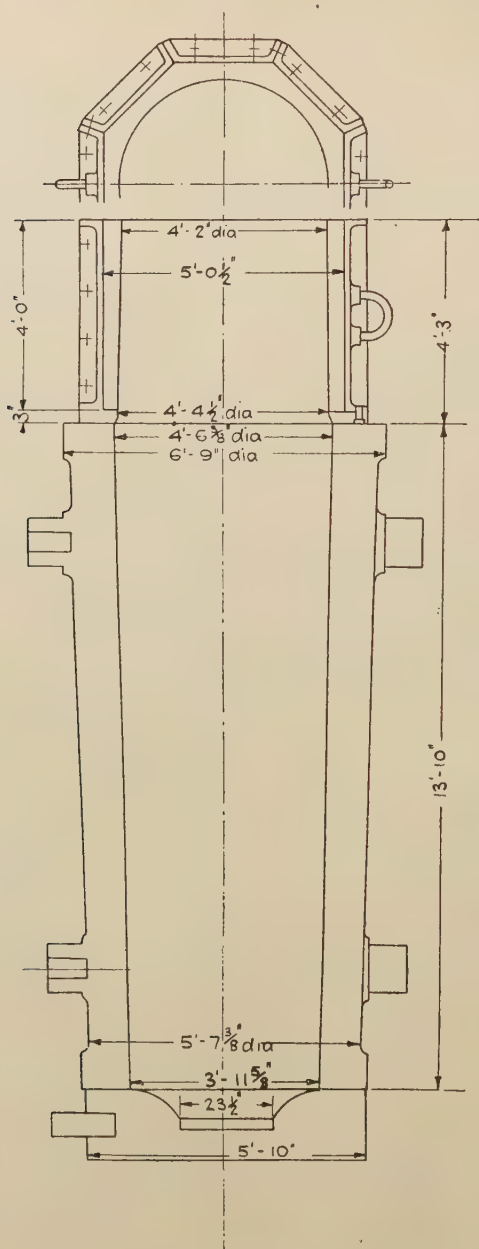


FIG. 17.—Mould Q.

	Tons	cwt.
Total weight of ingot	50	3
Weight of chill portion of ingot	40	8
“ “ “ “ “ “ mould	41	4

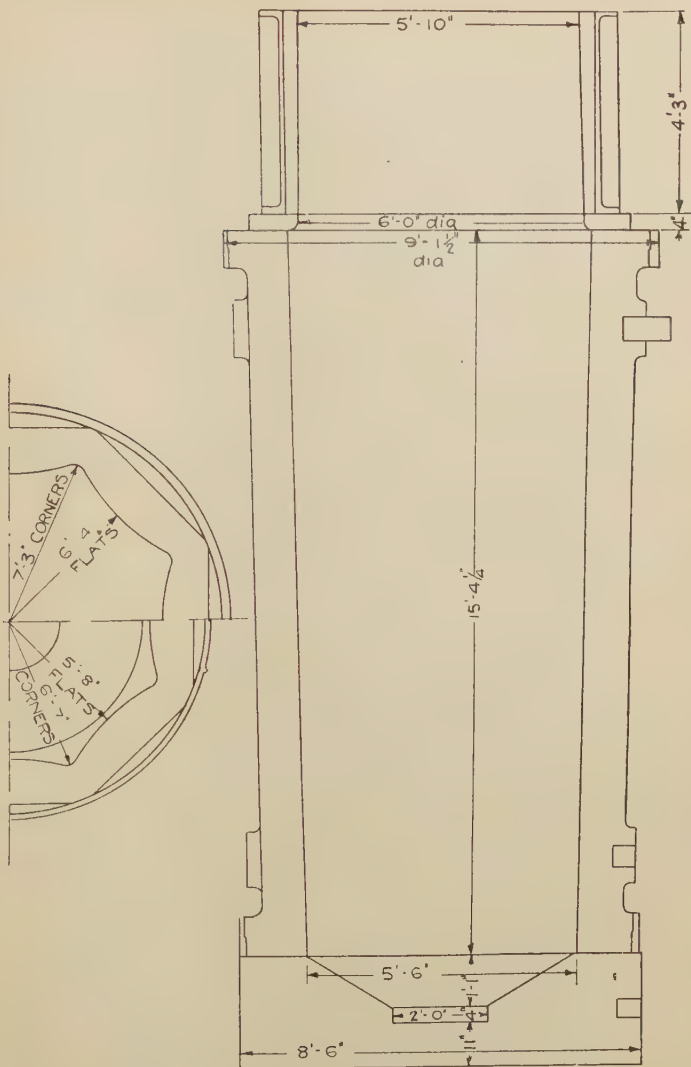


FIG. 18.—Mould R.

	Tons	cwt.
Total weight of ingot	119	10
Weight of chill portion of ingot	96	10
" " " " " mould	64	2

The macrostructure shown in Fig. 19 (Plate XXIII.) illustrates, in a general way, the change gradually taking place in the iron at the ingot surface. The type of iron used is invariably that which will cast "grey," and its actual analysis is frequently determined by the desirability of melting up the old moulds in the steel-making furnaces which they are serving. Hard or white cast iron is unsuitable, owing to its brittleness, and to its readiness to fracture under stresses resulting from unequal heating, which is a necessary condition of service.

The following values for the physical properties of iron employed for ingot moulds are stated for later use in regard to the general problem under consideration :

ρ = specific gravity = 7.2.

s = specific heat = 0.125 cal. per grm.

k = thermal conductivity = 0.11 cal. per sq. cm. per sec. per ° C. per cm.

h = coefficient of radiation (according to Newton's law of cooling) = 9×10^{-4} cal. per ° C. per sq. cm. (at 300° C.).

Some of these data can well be amplified, especially as to their values at high temperatures.

Functions performed by the Mould.

Primarily, the function of an ingot mould is to provide a receptacle for the molten steel, which shall, after freezing, be in a form suitable for subsequent working. A further function of the mould is to abstract heat from the molten steel, and to dissipate it by radiation, or other means, from its outer surfaces. The mould abstracts heat from the steel by two not entirely independent methods. The first is the chilling action, due to the mould being at a much lower temperature than the steel in it, and acting as a receptacle into which the heat is emptied from the steel. The second, which becomes the more vital as the cooling proceeds, is the outward passage of heat by conduction through the walls of the mould, with subsequent radiation from its outer surfaces. These two effects are very important and will be further discussed.

The above are the essential functions of an ingot mould, but it has necessarily become more and more the practice so to design the mould that it may fulfil the further function of producing sound

Inside surface of mould.



FIG. 19.—Macrostructure of used ingot mould showing decarburisation of the inner surface extending to some depth. (Full size.)

ingots free from cavity with the harmful influence of the segregation phenomena reduced to a minimum. The form of the ingot mould should also be such that the amount of steel to be discarded from the ingot may be as small as possible.

Characteristics of Representative Moulds.

A brief survey of the designs of moulds employed for the ingots under discussion is useful at this stage. The moulds *A*, *C*, *D*, and *F* are those used for producing the smaller alloy steel ingots. They all have superimposed refractory-lined feeder-heads, the walls of the mould are suitably increased in thickness towards the bottom, and the cross-section of the ingot is greater at the top than at the bottom. At the position XX, half-way down the chill portion of the ingot, a square foot of the mould covers much less than its own weight of liquid steel, the percentage relationship of the weight of the mould to the steel being of the order of 133 to 204 per cent. This decreases upwards and increases downwards, thus ensuring that the freezing of the steel is less rapid as the mould is ascended. The moulds *N*, *O*, *P*, *Q*, and *R* are those used for the larger forging and alloy steel ingots, and in general principles will be seen to conform with the smaller moulds just discussed. They all have refractory-lined feeder-heads, and are larger in internal section at the top than at the bottom. Although the walls of the mould do not increase in thickness down the chill, still in every case the local ratio of weight of mould to the quota of steel which it covers increases down the ingot owing to the decreasing sectional area of the ingot. At the position XX, the percentage weight of the mould to the steel in these larger ingots is of the order of 98 to 119 per cent.

Moulds *E*, *G*, *H*, and *I* are used for carbon steels.

Moulds *J*, *K*, *L*, and *M* are of particular interest, being the moulds used in casting ingots from non-piping steel. No feeder-head is provided, and the ingots are usually heavier in section towards the bottom than towards the top. The mould walls are practically of uniform thickness and partially form a chill top. At the position XX the weight of mould covering its quota of steel is much less than that of the steel, the relationship being

of the order of 68 to 85 per cent., which is considerably less than is the case with the other type of moulds, particularly the smaller sizes.

Mould *B* is included as an example of moulds used in large quantities years ago when ease of manipulation was placed before quality of product; the reason for discarding such a form of mould was not so well appreciated then as now.

Considerations in the Design of Moulds.

Any factor which influences the functioning of the mould as above discussed is of importance in estimating its weight and dimensions. Such factors are numerous and are not confined to the properties of the mould itself, but are inherent also in the steel inside the mould. Economic factors also enter, in that it may be advisable in some cases to sacrifice the advantages of using a certain shape of mould in order to simplify and considerably reduce the cost of the subsequent working of the steel ingot. The relative importance of many of these factors, too, is not very definite, so that it is often extremely difficult to decide *a priori* which of two ingot moulds is the better for a particular purpose. It is only possible to enumerate the various factors which operate, and the direction in which they act, and then perhaps, from a general review, arrive at conclusions.

In the design of the shape of the mould, five points concerning the ingot must be borne in mind:

- (a) Freedom from cavity.
- (b) Suitability for and ease of further working.
- (c) The stresses set up on cooling.
- (d) The elimination, if possible, of planes of weakness.
- (e) The layout of the segregate.

The freedom from cavity depends on the supply of sufficient molten material to fill up the spaces produced by contraction, and the prevention of isolated lakes of molten material. The former is controlled by the design of the feeder-head, and does not concern the mould itself. The latter is influenced by the relative rates of cooling of the various portions of the ingot, the change in dimensions on freezing, and the coefficients of expansion

of both the solid and molten materials, and the design of the mould. Ingots with the narrow end at the top are most likely to produce these isolated lakes ; ingots with the wide end at the top reduce this possibility. The correct taper is difficult to decide, as it depends on the rates of cooling at the freezing temperature in the various parts of the ingot. The taper should be such as to make possible efficient feeding of the body of the ingot.

Segregation.

The phenomenon of segregation depends not only on the chemical composition of the steel in the ingot, but also on the rate of cooling, both of the ingot as a whole, and of each individual point in the ingot. For example, and referring more particularly to piped ingots, near the walls of the ingot, where the rate of cooling is rapid, the segregated impurities are trapped in the rapidly growing crystals. Further inside the ingot, where the cooling is slower, the segregates will collect together and produce the so-called ghosts, or they may tend to rise to the surface and collect in the scrapped ingot head. Of importance also are, naturally, the thermal conductivity, density, and specific heat, which are all more or less affected by the chemical composition of the steel.

Dependence of the Rate of Cooling upon the Characteristics of the Steel and of the Mould.

The thermal conductivity of the ingot material, its specific heat and density, affect the rate at which heat can be extracted from the centre of the ingot. The greater the value of $\frac{k}{\rho s}$ (k = thermal conductivity, ρ = density, s = specific heat), the smaller will be the temperature gradient in the ingot at any particular place at a certain time after casting, and the lower will be the temperature at that place. The rate of cooling at any particular place, when it has reached a certain temperature (say, freezing temperature), will also be proportional to this expression, other things being equal. Apart from determining the internal dimensions of the mould, the coefficient of expansion has a secondary influence ; the greater total contraction of the

ingot material, as compared with the ingot mould, causes the former to separate from the latter, leaving a space between the two. The influence of this upon the rate of cooling is somewhat doubtful, but it is probable that the greater portion of the heat will be transferred by radiation, so that the effect is of little significance. The amount of the initial chilling action of the mould will depend on the relative specific heats of the ingot and mould materials. As, however, the specific heats of all ferrous materials are very much the same, the differences produced by variations in this factor may be neglected in this connection.

For moulds of the same dimensions, the greater the conductivity, the greater will be the rate of cooling. The thickness of the mould walls affects the amount of the chilling effect of the mould, which increases with increasing thickness. Owing to the finiteness of the conductivity of the materials, however, the increase will not be proportional, but will tend to a limiting value. In the later stages, the rate of cooling of the ingot will be reduced by the increased thickness.

Planes of Weakness in the Ingot.

Planes of weakness are caused where the crystals growing from two faces meet. They are bound to occur in those portions of the ingot where the freezing produces columnar crystals. Therefore, the closer the internal shape of the mould conforms to that of a cylinder, the less will be their effect. Circular ingots, especially in the larger sizes, however, are prone to stress cracks. Octagonal or hexagonal moulds have actually proved better for the larger ingots; except in the earliest stages, they freeze internally in very much the same way as they would in a cylindrical mould.

Stresses in the Ingot due to Cooling.

Owing to the difference in the rates of cooling of the outside and inside of the ingot, stresses are invariably set up in the cooling ingot, and they may be of such magnitude as to lead to cracks. These stresses increase with an increase in the temperature gradient across the section, and vary with different types of steel.

The design of the mould, therefore, both in shape and dimensions, must be such as to reduce this temperature gradient as much as possible, bearing in mind the other features of the ingot. In this respect the position and magnitude of the change points, if any, in the steel are of importance. The lower the temperature at which they occur, and the greater their magnitude, the greater will be the stresses produced. There are other factors which influence the rate of cooling of the ingot and, hence, the design of the ingot mould—for example, the temperature of the outside atmosphere and the rate of radiation from the walls of the mould, but as the variations in these are small, they may be taken to be constants.

As regards the stresses and planes of weakness, as the ingot cools the outside tends to contract at a greater rate than the inside, at any rate during the earlier stages, while the temperature gradient is changing. Tensile stresses are therefore set up in the periphery, and may be sufficient to produce cracks there. Later on, when the outside has become comparatively cold and the inside is still cooling, the nature of the stresses is reversed. The tensile stresses are then present in the middle of the ingot. The magnitude of the stresses depends on the relative rates of cooling of the inside and outside of the ingot. A thick mould might, therefore, be expected to increase the stresses in the early stages, but later on it would cause a slower and more uniform rate of cooling throughout the ingot, which would tend to decrease the stresses. Stresses, too, are produced by the passage of various parts of an ingot through the critical ranges at different times. Many factors enter here, such as the temperature distribution and the influence of the rate of cooling on the actual temperatures of the transformations. These are determined by the chemical composition, which also influences the magnitude of the changes that occur along with them.

Necessary Empiricism in Design.

Such, then, are some of the factors which must be taken into account in determining the weight and dimensions of an ingot mould. A mathematical treatment of the subject is extremely difficult, and solutions can only be obtained, even in the most

simple cases, by neglecting various terms, such as variations in the physical properties with temperature, latent heats of fusion, and other critical thermal changes, &c. Even when simplified in this way, the mathematical expressions arrived at are intricate, and can only be solved with difficulty by graphical methods. Apart from these mathematical difficulties, in order correctly to design an ingot mould, bearing in mind the factors enumerated above, one must first be satisfied as to the best rate of cooling and temperature gradient across the ingot, especially at the period when the material is at the point of freezing. It will naturally vary at various places in the ingot. Further, the best rate of cooling may be different for different steels. In other words, the design of the mould will depend on what is desired in the finished ingot. If an ingot be required in which the amount of columnar crystals is to be as large as possible, then the thicknesses of the walls should be adequate. Without knowing, however, the rates of cooling which give rise to the formation of the columnar crystals, the thickness of mould wall cannot be predicted. It would appear that the limiting depth of these crystals is already reached with fairly thin walls, so that any increase in thickness of mould wall beyond this has very little effect. It has been suggested that the influence of varying thickness of mould may be divided into three stages: (1) The initial stage, in which there is the sudden drop in temperature at the outer surface of the ingot, due to the chilling action of the mould; (2) an intermediate condition, when the mould has become heated and there is a more or less gradual change in the temperature at the interface between ingot and mould; (3) the final stage, when the ingot and mould cool together, almost as if they had become one integral mass—that is to say, when the mould has practically lost its initial function as a receptacle of heat and become simply a conductor. The thickness of the mould will operate in different directions in the three stages, between which there is, of course, no sharp division. At the commencement of the first stage—that is, as soon as the liquid steel is poured into the mould—the outer skin of the ingot and the inner skin of the mould rapidly approach the same temperature. This temperature is independent of the thickness of the mould, and is determined mainly by the initial temperatures of the steel as cast and the mould.

Conclusion.

It appears that even if a complete mathematical expression could be given to represent the freezing of the ingot in the mould, there would still be considerable doubt as to how to apply it, until agreement is attained as to the best crystalline arrangement to aim for, and even then the influence of the rate of cooling, or of the velocity of freezing across the section, on that crystalline arrangement must be known. It is therefore clear that for the present the Committee can well leave the matter as one requiring much further elucidation, and simply present the data of the actual moulds concerned in the production of the ingots under discussion.

SECTION III.—*Certain Features of Steel Manufacture which may Influence Heterogeneity.*

Although it is not considered within the terms of reference of this Committee to investigate steel-making processes, a study of the heterogeneity of steel ingots would not be complete without due consideration being given to three important factors, each of which depends essentially upon the process of manufacture employed—namely, the presence in the ingot, and the origin of :

- (1) Oxides and silicates.
- (2) Sulphur, phosphorus, and extraneous elements.
- (3) Gases.

Oxides and silicates, which occur as non-metallic inclusions, apart from causing obvious defects when badly segregated, even when dispersed as small inclusions, lead, in exaggerated cases, to the production, as a result of hot-work, of "woody" fractures.

As regards the presence of sulphur, structurally free sulphides of manganese or of manganese and iron (or possibly of even more complex composition) have the same general effect as other non-metallic matter in destroying the continuity of the metallic aggregate, particularly on account of their facility for segregation. Phosphorus also, owing to the readiness with which it segregates, should be as low as economic and process considerations permit.

The effects of the presence of other extraneous elements such as arsenic and copper need further investigation.

With regard to the presence and influence of the gases remaining in solution in the solidified steel, it must be confessed that little exact knowledge is available, and that much work requires to be done.

A more complete understanding of the physical chemistry of steel-making would make possible a better control of these factors. In each type of process the temperature of the raw material is raised until the conditions are such that a liquid metal is in contact, and reacting, with a superimposed layer of liquid slag. The variable composition of the metal and of the slag, the variation in temperature, and also in the composition and volume of the gases reacting upon the metal charge during melting, and afterwards upon the upper surface of the molten slag, all introduce complications which render the study of the nature of the reactions extremely difficult. Some processes have been studied more intensively and successfully than others. In no case, however, is knowledge sufficiently complete to enable an arbitrary statement to be made concerning the actual or the optimum effect attainable with respect to the three important factors under consideration.

The present steel-making processes were devised and developed mainly on empirical lines, and it is only of late years that refinements in procedure have been found to be necessary in order to secure the higher degree of homogeneity which is desirable in the finished steel. This aspect may be illustrated by the fact that the Bessemer and the Siemens-Martin open-hearth processes were not successful until substantial quantities of manganese alloyed with iron were added to the refined steel as the last stage of the process. The opinion is held that if a slag containing oxide of iron be superimposed on a bath of liquid iron, some oxide of iron will go into solution in the metal. It is not known, however, to what extent the presence of carbon and other elements in the bath affects the equilibrium value of the oxide content.

Much of the large tonnage of steel made is tapped with the slag relatively high in oxide of iron, and the manganese and silicon, alloyed with iron, are added in the solid form to the liquid steel as it issues into the ladle. Assuming, therefore, that oxide of iron is present in the liquid steel, the reaction with the manganese and

silicon presumably produces insoluble oxides dispersed through the liquid in the ladle in an extremely fine state of division. The present view is that the silicate of manganese produced from the union of these two oxides constitutes the most serious form of non-metallic inclusion. The incompleteness of knowledge on this subject, however, is illustrated by the work of Stead, Dickenson, and others, which disclosed that some of the silicates isolated from acid open-hearth steel did not consist entirely of manganous silicate, but were probably complex silicates of manganese, iron, and other elements. The precise nature of the reaction between the added deoxidisers and the oxygen which is held to be present in the liquid steel is therefore not finally established.

Clearly, however, if the steel is "finished" in this manner, the amount of the silicate present in the finished steel will be dependent upon the composition of the slag, since the oxygen content of the steel depends upon the equilibrium ratio between the oxygen in the slag and the oxygen in the metal. These comments apply to both the acid and to the basic processes.

The improved understanding of the physical chemistry of the processes has led to alterations of procedure in regard to certain classes of steel, notably in producing killed or piping steel by the acid process.

When acid open-hearth "piping" or solid steel is produced, as typified in certain of the ingots in the First Report, then the slag is usually permitted to acquire a high acidity by the combined effect of time and temperature, and the cessation of oxide additions, with the consequence that the slag, and presumably the metal, attains a lower oxide content. Further, the manganese and silicon additions are made in the furnace some time before tapping, and it is therefore presumed that the steel will be cleaner owing to the precipitated oxides and the silicates formed being able, in some degree, to rise from the metal bath and join the slag. Nevertheless, such steel never is entirely freed from oxide and silicate inclusions.

The nature of the reactions of the basic process renders inadvisable any attempt to reduce the amount of "included" slag by adding silicon to the melt in the furnace, since under certain conditions a reaction ensues which causes an increase of the phosphorus content of the steel. It is, however, sometimes the

practice in the basic process to add ferro-manganese in the finishing stages of the heat, with the object of minimising the degree of oxidation of the metal, and consequently the amount of inclusions. The steel-maker necessarily works within limitations which are imposed upon him by the physical chemistry of the particular process.

The operation of the acid and basic Bessemer processes involves analogous considerations, but it can hardly be doubted that the effect of overblowing is to increase the amount of silicate inclusions.

As regards the electric process, it can be stated that although its physical chemistry is not fully investigated, better facilities exist for deoxidation than in any of the other processes discussed, and that this does, in fact, lead to an improvement in practice. This is due to the fact that in the basic-lined electric furnace a completely "reducing" slag can be produced during the later stages of the process, so creating conditions such that the oxides of iron, manganese, and chromium in the slag are reduced to very low values, and the deoxidation of the metallic bath accomplished. Sufficient has been said to point out the importance of the bearing of furnace reactions upon the heterogeneity of ingots, and in the present Report some information will be found, indicating, for record purposes, the nature of the final finishing conditions.

The question of the gas content of the steel, and its influence upon the steel during freezing, is fundamentally important. The present state of knowledge permits of little discussion. It must be assumed that the molten metal has absorbed gas during the process, which tends towards an equilibrium value for the particular conditions existing in the furnace, but it is not established that the gases given off from the steel represent the composition of the gases which were in solution. It may, however, be stated that evidence tends to show that the gases contained in blowholes, and also those evolved from solid steel when heated *in vacuo*, consist of hydrogen, carbon monoxide, and nitrogen. The presence of sufficient silicon and manganese in the steel at the moment of freezing decreases the amount of gases evolved during the critical stage of freezing, thus preventing the formation of blowholes. Aluminium has a similar effect, and produces alumina, which may remain in the steel as non-metallic inclusions. As will be shown in Section V., the evolution of gases during the freez-

ing range appears to have a material effect upon the distribution of the segregating constituents within the solid steel.

With regard to the non-metallic matter which is found included in steel, there has been much discussion as to the part played in producing these inclusions by atmospheric oxidation of the liquid steel subsequent to its leaving the furnace. In the first place, it is by no means definitely established that such oxidation takes place to any serious extent, except on the rising surface of the liquid steel in the mould ; and, secondly, if it does take place, that the oxides so formed largely remain entangled in the steel. Small particles of refractory material, picked up or eroded from the launder, or from the ladle stopper or runner bricks, may become associated with the silicates or remain entangled in the solid steel. In passing, it may be well to observe that steel-makers fully realise that cleanliness, such as the freedom of moulds, &c., from loose dirt and dust, is essential.

Temperature Control and Measurement.

The Committee desires to draw attention to those important matters, the determination and control of the temperature of liquid steel. The temperatures existing in the furnace are fundamentally important in their effect upon the reactions, and, therefore, upon those factors which have already been considered in this section. In practice, they are dealt with on more or less empirical lines. The casting temperature is, however, so important in the present connection as to be one of the determining factors, both of the distribution of segregation in the ingot and of its crystalline structure.

The observation of the temperature of liquid steel in a practical quantitative manner is a matter of special difficulty, and the only means industrially available for the purpose are optical or radiation pyrometers. To avoid the many errors to which these instruments are susceptible requires a careful understanding of the principles upon which they operate, and their intelligent and skilful use, often under conditions of considerable practical difficulty.

It is beyond the scope of the present Report to enter into all the details concerning the various sources of error ; some mention must, however, be made, because although temperature records

obtained by optical pyrometers are included in this Report, it is necessary to recognise fully their limitations. Temperature observations carried out in an individual works by a single operator give fairly concordant figures, but comparisons lose some value when attempts are made, as in the present instance, to provide essential data of general application derived from a number of different works. Special reservations should be made in regard to temperatures recorded of the interior of furnaces, and also of the stream when tapping electric furnaces, where the liability to error is particularly pronounced.

A further and important point is that optical pyrometers give an under-estimation of the true temperature of heated objects in the open, due to departure from what is known as "black-body conditions." The error in the case of molten steel is considerable. At similar temperatures, and under similar conditions, the correction is believed to be more or less constant, though it has not been determined with sufficient accuracy. For purposes of comparison it might be sufficient, therefore, to compare the observed temperatures where the conditions of observation are similar, but for the proper appreciation and discussion of the temperatures and their effects in the present connection it is necessary to express them in a closer approximation to their true values.

In the present Report the temperatures recorded for streams in the open—all determined by the optical pyrometer (generally of the Cambridge type)—include a uniform correction of 125° C. To readings taken inside the furnace, where black-body conditions are approximated to, no correction has been applied. In the absence of a thoroughly satisfactory basis of correction the Committee considered that the course adopted was the best, and this statement of the correction employed will enable those interested who use a different method to compare their own observations with the figures given.

Until the pyrometry of high temperatures under practical conditions, such as exist in steelworks, is more developed, the effect of temperature in the problems under consideration cannot be stated in a sufficiently quantitative way.

Fortunately, from the point of view of actual steel manufacture, the best melters are so skilful in judging, not only the temperature

throughout the process, but also the finishing temperature, that a much greater regularity of practice is attained than would otherwise be possible. The physical characteristics and appearance of the slag provide the melter with a very good guide to the conditions existing, including the temperature.

A bibliography of the temperature measurement of molten steel will be found in an Appendix to this section.

Casting Speed.

A factor of great importance in its effect upon the characteristics of an ingot, but which is more or less influenced by the casting temperature of the steel, is the speed of teeming. There is clearly a best speed of teeming for a given temperature. If very hot steel is poured very quickly, the internal stresses produced during freezing and subsequent cooling will tend to produce cracks in the ingot. If the steel is not hot enough and the speed of teeming slow, "cold lapping" results, and oxide formed upon the rising surface of the liquid steel in the mould tends to be entrapped in the ingot. The best speed of teeming is difficult to determine, since it will be influenced by the size of the ingot and, to some extent, by the character of the steel. Practical experience invariably leads to a standard method in each works, and it is by the comparison of the effects produced by the conditions existing in various works that valuable data can be derived.

The Ingots presented as Examples in the First Report.

At the outset the Committee was content simply to study the nature and degree of heterogeneity existent in the ingots submitted to it. The results of that study, presented in the First Report, made it desirable to attempt to determine the effect of the various factors, but it will be realised that time must pass before suitably comparable data can be obtained from the various works which are assisting in the investigations. Inquiries led, however, to the provision of some interesting items of information relative to the ingots in the First Report.

Example 2.—This ingot was cast from a 26-ton acid Siemens charge. The tapping temperature is described as "medium,"

and the slag as "fluid." Additions of 638 lb. of 80 per cent. ferro-manganese, 7 lb. of aluminium, and 36 lb. of anthracite were made to the ladle. A $1\frac{1}{4}$ -in. fireclay nozzle was used.

Example 4.—This ingot was cast from a 56-ton acid Siemens charge. The composition of the finishing slags before and after the additions were as follows :

	SiO ₂ . %	FeO. %	MnO. %	CaO. %
Before deoxidising additions	59·20	15·08	...	...
After deoxidising additions	61·20	14·39	12·18	9·75

The nozzle used was $\frac{7}{8}$ in. in diameter. The teeming temperature was 1480° C. observed (1605° C. corrected).

Example 5.—This ingot was made from a cast of steel which was tapped from the furnace at a corrected temperature of 1610° C. The ferro-manganese was added in the furnace, and the finishing slag contained SiO₂ 60·51, FeO 15·08, CaO 10·72, and MnO 8·84 per cent. It was a 70-ton charge, and 9 lb. of aluminium were added to the ladle. A magnesite nozzle 1 in. in diameter was used ; the ingot was poured at a speed of 1·07 tons per minute, and the feeder-head at 0·23 ton per minute.

Example 6.—This ingot was made from a cast tapped at 1590° C. (corrected temperature). The ferro-manganese was added in the furnace, and the finishing slag contained SiO₂ 58·56, FeO 12·28, CaO 10·04, and MnO 15·70 per cent. The charge weighed 70 tons, and 10 lb. of aluminium were added to the ladle.

Example 8.—This ingot was from a 62-ton charge. 672 lb. of ferro-manganese were added to the bath five minutes before tapping, and 840 lb. of ferro-manganese, 196 lb. of ferro-silicon (75 per cent.), and 12 lb. of aluminium were added to the ladle.

Example 10.—The finishing slag of this electric furnace heat was white and falling before and after casting. It is interesting to record that to a charge of 10,000 kg. 1 kg. of aluminium was added during casting.

The pit sample gave the following analysis :

	%
Carbon	0·30
Manganese	0·74
Silicon	0·13
Sulphur	0·017
Phosphorus	0·01
Nickel	0·36
Chromium	0·06

Example 11.—This ingot was cast from a 47-ton acid Siemens charge. The additions were made to the furnace, and the finishing slag, before the additions, had the following composition :

						%
SiO ₂	.	.	.	.	.	54.8
FeO	.	.	.	.	.	11.6
MnO	.	.	.	.	.	21.95
CaO	.	.	.	.	.	9.18

The ingot was teemed at a temperature of 1465° C. observed (1590° C. corrected). A $\frac{7}{8}$ -in. diameter nozzle was used. About 25 minutes were taken in teeming.

Example 12.—This was a 25-ton ingot cast from a charge weighing 54 tons which was tapped from the furnace at a temperature of 1590° C. (corrected). The temperature of the steel as it was poured from the ladle was 1540° to 1545° C. (corrected). The ferro-manganese and ferro-silicon additions were made in the furnace, and after the last additions half an hour elapsed before tapping. The SiO₂ content of the slag at the time the additions were made was 56.5 per cent., and analyses of samples showed that the bath of steel was in such a condition that silicon and manganese were being reduced into it from the slag. No aluminium was added to the ladle. The ingot was cast over a period of 18 minutes, thus averaging a speed of 1.39 tons per minute.

SECTION III., APPENDIX.—*Bibliography of the Temperature Measurement of Molten Steel.*

- C. C. BIDWELL : "Actual and Black-Body Temperatures." *Physical Review*, 1914, vol iii., Series 2, June, pp. 439–449; abstract, *Science Abstracts*, 1914, vol. xvii., [A], p. 539.

(Comparisons are made between the actual and black-body temperatures of iron, gold, silver, copper, and nickel, both solid and liquid, over the range 1000° to 2000° absolute. The iron was heated in a crucible, and the carefully calibrated Morse optical pyrometer, in which light as nearly as possible monochromatic of wave-length 0.66 μ was used, was directed towards the metal surface and towards a neighbouring air cavity in quick succession, the readings giving the black body and the actual temperatures respectively. When the solid surface was obtained by freezing the molten metal, care being taken to avoid all traces of oxide, continuous curves were obtained for the passage from the solid to the liquid state. Solid surfaces prepared artificially always showed a sudden drop in emissivity on melting. Solid iron has a fairly constant emissivity, but that of solid nickel decreases with increasing temperature, the coefficient being 0.000125. With both molten iron and molten nickel there is a rapid increase in emissivity with temperature, which is attributed to the solution of carbon.)

C. C. BIDWELL : "Thermo-Junction of Carbon and Graphite." *Physical Review*, 1914, vol. iii., Series 2, June, pp. 450-452; abstract, *Science Abstracts*, 1914, vol. xvii., [A], p. 552.

(A thermo-junction of carbon and graphite designed to measure the temperature of molten metals beyond the reach of the platinum/platinum-rhodium thermocouple is described. Rods of carbon and graphite 30 cm. long and 2 mm. in diameter have pointed ends, which are brought close together in the molten metal. The cold ends are fitted to heavier rods 50 cm. long, which are connected by copper leads to the galvanometer. The e.m.f. of the couple is large, being approximately 0.02 microvolt per degree, and is nearly linear up to 2000° C. It is, however, somewhat erratic unless the rods are previously heated up to 2000° C., at which temperature all impurities affecting the e.m.f. are given off. When the couple is used in air the rods gradually oxidise just above the surface of the molten metal, so that new points have occasionally to be made. A disadvantage is that when this occurs a new calibration is needed. If rods of greater purity and protected from oxidation were used a serviceable instrument might be made.)

G. K. BURGESS and P. D. FOOTE : "The Emissivity of Oxidised Metal Surfaces." *Bulletin of the U.S. Bureau of Standards*, 1914, vol. ii., No. 1.

(The authors employed an ordinary Fery radiation pyrometer for the measurement of the radiation, calibrated to give true temperatures under black-body conditions. Observations were made of the apparent temperatures, and a simple expression is calculated for determining the emissivity :

$$E = \left(\frac{S}{T} \right)^4$$

in which E denotes the total emissivity of an approximately non-selective radiating surface at absolute temperature T , and S the apparent temperature observed with the radiation pyrometer. Since in practical types of radiation pyrometers the index is rarely exactly 4, the above expression requires slight modification in such cases.

To obtain the true temperatures corresponding to the apparent temperatures, two methods were available which gave results in close accord :

(1) The application of the idea embodied in the Joly maldemeter, in which the melting points of microscopic specimens of various substances were observed, such as sodium chloride (800° C.), sodium sulphate (884° C.), and gold (1063° C.). Experiments were made to ascertain that the temperature of the strip did not differ appreciably from that of the specimens.

(2) By the use of an optical pyrometer calibrated to read true temperatures when sighted on such a surface. This pyrometer is based on the principle of matching the intensity of the light from an electric lamp filament with the light from the hot object.)

W. H. HATFIELD : "Notes on Pyrometry from the Standpoint of Ferrous Metallurgy." *Transactions of the Faraday Society*, 1918, vol. xiii.

(Experiments were carried out on a number of heats with the thermoelectric and with the Cambridge optical pyrometers. The optical pyrometer was sighted upon the steels running into the ladle, and values were obtained in the neighbourhood of 1400° to 1410° C. (low and high range scales for the same instrument). Comparative readings were taken with the thermocouple pyrometer, a couple being placed in position in the empty ladle prior to the steel being run in. As the steel gradually filled the ladle the temperature indicated by the thermocouple increased, until the couple was thoroughly immersed in the molten steel. The steel was

then tapped from the ladle, the metal receding until the couple was quite free from the molten steel. By this means a time-temperature curve was obtained in which a flat maximum range was observed, corresponding to the temperature of the steel whilst in the ladle. There was a difference of something like 150° to 200° C. in the two kinds of readings, and the temperatures so stated might be taken to indicate the apparent disparity between the two methods of approach. It is appreciated that a correction is necessary in the case of the optical pyrometer for imperfect black-body conditions, and such a recognised variable error will have to be put upon a quantitative basis before optical readings can be thoroughly utilised where small variations at very high temperatures are important. One problem, for instance, is of considerable interest—namely, does the emissivity of steel vary with the condition independent of temperature ?)

J. N. GREENWOOD : "Applications of Optical Pyrometry in Steelworks Practice." *Transactions of the Faraday Society*, 1918, vol. xiii.

(The various conditions of use of an optical pyrometer in taking the temperature of liquid steel in the open are compared with the calibration conditions, and are shown to differ widely from them. The errors due to the deviations fall into two classes. To the first class belong errors due to emissivity and polarisation of the emitted light. To the second class belong such as are due to lack of monochromatism of the absorbing screen (absent in such types as the Wanner), to fumes, to light reflected from external sources, and to smallness of the source of light. Several technical defects of the Cambridge optical pyrometer are considered. In order to obtain control of the steel-making process pyrometrically, a refractory tube should be inserted into the bath when it is required to take the temperature. A true black-body condition would then be very nearly approached.)

COSMO JOHNS : "The Determination of the Temperature of Liquid Steel under Industrial Conditions." *Transactions of the Faraday Society*, 1918, vol. xiii.

(In the manufacture of acid open-hearth steel a trained observer using a correct type of pyrometer can obtain readings of sufficient accuracy. Under the most favourable conditions the apparent temperature can be read to within $\pm 3^{\circ}$, and under normal conditions to less than $\pm 5^{\circ}$. As divergences from a determined "normal" are sufficient for this control,

Corrections to Add to Optical Pyrometer Readings at Various Temperatures and Emissivities. Pyrometer using Red Light, $\mu = 0.70$.

e = Emissivity.	Temperatures Observed—						
	1350° C.	1400° C.	1450° C.	1500° C.	1550° C.	1600° C.	1650° C.
	° C.	° C.	° C.	° C.	° C.	° C.	° C.
0.40	125	134	142	151	160	169	179
0.50	93	99	105	112	118	125	132
0.60	68	72	77	81	86	90	95
0.65	57	60	64	68	72	76	80

these pyrometer readings can be used to determine temperature differences without importing any serious error.

The most suitable instrument is an optical pyrometer, using monochromatic light $\lambda = 0.65 \mu$, which, it is suggested, should be adopted as

a standard. It should have a scale that can be read, under industrial conditions, to 2°. The observer should be able to read to $\pm 5^\circ$.

Observations on clean surfaces of liquid steel can only be made when the steel is in motion. Any determination of apparent temperature will therefore only refer to the particular surface that was under observation at the instant the reading was made. All such moving surfaces are rising or falling in temperature, so that the relative time at which the observation was made is an important factor when comparable results are desired.)

- A. McCANCE: "Temperature Determinations of Liquid Steel." *Transactions of the Faraday Society*, 1918, vol. xiii.

(In determining the temperature in an open-hearth furnace, the apparent temperature recorded by an optical pyrometer will be the true temperature plus an amount which will depend on the temperature of the flame and the reflective emissivity of the slag surface. It was decided after experiments that the best places on which to focus the instrument were the slag surface opposite the port by which the gas was entering, and the furnace roof immediately above this. At first variations from 1550° to 1700° and over were found. Ultimately it was found that by means of temperature observations the temperature could be kept between fairly close limits running from about 1630° to 1650° apparent temperature, with advantage to the life of the linings.)

- G. K. BURGESS: "Temperature Measurements in Bessemer and Open-Hearth Practice." *U.S. Bureau of Standards, Technologic Paper No. 91*, 1917, pp. 1-29; abstract, *Journ. I. and S.I.*, 1917, No. II. p. 406.

(Describes experiments on the pyrometric control of furnaces. The observations were taken with the Holborn-Kurlbaum form of Morse pyrometer, using monochromatic light, and permitting observation of streams of metal from a distance. A table of emissivity corrections is given in the report. It was found possible to control readily the temperature of the roof and of the bath of metal and slag by observations through ports, and the temperature of the metal may be taken at any instant with a fair degree of exactness by observation of the surface of 50 lb. of metal removed in a spoon. The temperature of the roof, dependent on the firing practice, may vary very rapidly and within wide limits, for instance, from 1550° to 1750° C., while the temperature of the bath usually remains between 1600° and 1670° C. There appears to be a remarkable degree of uniformity in casting temperatures actually acquired by melters, but it is believed that a systematic following of the temperatures in furnace and casting practice would lead to greater certainty in the quality of the product.)

- ANON.: "The Determination of the Temperature of Liquid Steel under Industrial Conditions." *Rassegna Mineraria, Metallurgica e Chimica*, 1919, vol. li. pp. 27-29; abstract, *Chemical Abstracts*, 1921, vol. xv., March 20, p. 820.

(The precautions to be observed in the practical measurement of temperature in an open-hearth furnace are enumerated. It is recommended that the instrument be placed at a distance of 4 m. or less from the flowing steel. At greater distances the temperatures may appear too low (by as much as 40°), due to the intervening smoke and fumes and to the fact that the field of the instrument may not be completely filled. Some actual measurements with a Féry radiation pyrometer are recorded, and the true temperatures are calculated from the apparent temperatures, on the assumption that the emissivity of the slag is 0.50 and that of the steels is 0.40.)

F. W. BROOKE: "Measuring Temperature of Molten Steel." *Blast-Furnace and Steel Plant*, 1919, vol. vii. pp. 597-599; abstract, *Chemical Abstracts*, 1920, vol. xiv., March 20, p. 724.

(Thermocouples are valuable in heat treatment but fail for melted steel, principally on account of the lack of suitable refractories. Radiation and optical pyrometers (the author prefers the first as less subjective) are rendered unsatisfactory by the presence of slag or incandescent gases or smoke. Three other methods are described: (1) The time elapsing before an oxide film forms on the clean melted metal is noted; (2) whether a cooler iron rod immersed in the melt gathers iron in a given time or is melted away is observed; (3) how a sample of iron pours from a small ladle is watched—this is the test most used. All these give only comparative results, and depend on great uniformity of conditions.)

"PYROMETRY." The papers and discussion of a symposium on pyrometry held by the American Institute of Mining and Metallurgical Engineers, Sept. 1919.

Among the sixty papers contained in this volume are the following:

- (1) G. K. BURGESS: "Report of Pyrometer Committee of National Research Council," p. 3.

(The use of Acheson graphite, either in block or tube form, as a target after immersion to the desired depth in the metal bath and sighted upon by the optical pyrometer, gives promise of being a serviceable method of temperature control. This graphite has the advantage of remaining clear of slag, and, in addition, the optical pyrometer requires no correction when sighted on graphite whether within the furnace or not.

Another method, used by Dr. Northrup with small laboratory furnaces, is to thrust a quartz-glass rod or thick-walled closed-end tube into the bath to the depth at which the temperature is wanted, then sight into the outer end of the rod with an optical pyrometer. The light being totally reflected along the quartz—which may even bend considerably without loss of light—temperatures not requiring any appreciable correction should be given by this method. The quartz will probably not last very long, especially in basic practice, but it will probably be found unnecessary to leave the quartz immersed more than a fraction of a minute in order to take a satisfactory observation. If held too long in the bath the quartz will of course melt. An investigation of the emissivity of crucible steel showed that, under industrial conditions, the values for the emissivity of steel and slag are 0.40 and 0.65 respectively.)

- (2) P. D. FOOTE and C. O. FAIRCHILD: "Optical and Radiation Pyrometry," p. 324.

(When an optical pyrometer is sighted on a glowing material in the open, it reads too low. Certain materials have a high emissivity, so that the corrections necessary to add to the observed temperatures are small; for example, for iron oxide the correction is only 10° at 1200°, but the corrections are very large for clear molten metals. A table shows the true temperatures corresponding to the temperatures observed when sighting on certain materials in the open.)

- (3) F. E. BASH: "Industrial Applications of Disappearing-Filament Optical Pyrometer," p. 353.

(It is questionable how close the temperature of the slag surface is to the steel temperature in an open-hearth furnace. Sometimes the steel is hotter and sometimes colder than the slag, depending on furnace conditions. Tapping temperatures can be taken very readily by sighting on the steel or slag stream and applying the corrections for an emissivity of 0.40 for steel and an average emissivity of 0.65 for slag. Curves showing the relation between true and apparent temperatures are given for slag and steel. Teeming temperatures can also be taken very readily by sighting on the metal stream from the ladle and thus obtaining the temperature at which each ingot is teemed.)

- (4) A. H. MILLER: "Pyrometry and Steel Manufacture," p. 567.

(The best method of bath-temperature determination seems to be that of sighting an optical pyrometer either on the surface of a spoonful of metal drawn from the furnace or on a stream poured from a spoon. The elapsed time between the drawing of this sample from the bath and the reading of the temperature should be noted, and the temperature of the bath deduced from the temperature of the sample and this time.)

- (5) F. E. BASH: "Electric, Open-Hearth, and Bessemer Steel Temperatures," p. 578.

(The tapping temperatures were taken of steel from electric furnaces of different sizes and from open-hearths handling the same kind of steel. All temperature measurements were made with the same disappearing-filament type of optical pyrometer, and the corrections for emissivity applied were those worked out by Burgess. The greatest variation in tapping temperatures was only 24° C., while the average for all the electric furnaces was 20° C. lower than for the open-hearths, although it is generally thought that open-hearth steel is tapped colder than electric.)

- C. JOHNS: "Surface of Liquid Steel." *Paper read before Section B of the British Association*, Sept. 1921; *Engineering*, 1921, vol. cxii, p. 619.

(An optically clean surface can be observed to persist for an appreciable length of time on liquid steel as it flows from the launder of an acid open-hearth furnace. The higher the temperature of the steel the longer does the liquid steel preserve its oxide-free surface, but, as the freezing point is approached, an oxide film begins to form and soon covers the surface. The preservation of the optically clean liquid metal surface is attributed to the presence of the vapour of the metal, and the subsequent formation of the oxide film to the lowering of the vapour pressure as the freezing point of the liquid metal is approached.)

- J. N. GREENWOOD: "Determination of the Corrections to Optical Pyrometer Readings taken during Steel-Making and Casting." *Iron and Steel Institute: Carnegie Scholarship Memoirs*, 1923, vol. xii, pp. 27-74.

(In open-hearth working evidence was obtained that the optical pyrometer in use was giving low results. A calibration of the pyrometer was carried out on a black-body furnace. It was found that there was an average difference of approximately 40° C. between the apparent temperature of the flame and the slag surface, and also there was an apparent fall of 30° C. when the flames cleared from the hearth during a reversal. From the average of a large number of readings it was concluded that in 88 per

cent. of the cases, if 32° C. be deducted from the temperature taken with gas on, the results will be the same as if luminous flames had been absent. This correction has been found to hold for acid and basic charges at all stages of working.)

B. M. LARSEN and J. W. CAMPBELL: "Optical Pyrometer Measurements in Open-Hearth Furnace." *Paper read before the American Institute of Mining and Metallurgy*, Oct. 1926.

(After a review of previous investigations and possible errors in optical measurements, the apparatus and method used in the investigation are described. The conclusions are that all surfaces are at practically the same temperature during steel-making, due to the speed of radiation exchange. As the bath comes up in temperature, the furnace chamber approaches black-body conditions, especially near the end of the heat, making "flame-off" optical temperatures very nearly accurate. Surface temperatures must be read at once after flame shut-off. Flame reflection always raises the apparent temperatures of wall and slag surfaces. The range of safe steel-making temperatures is given for silica arches or walls, and finishing temperatures for slow-working and fast-working furnaces.)

M. WENZL and F. MORAWE: "Temperature Measurements in Liquid Iron and Steel." *Stahl und Eisen*, 1927, vol. xlvii. pp. 867-871; abstract, *Chemistry and Industry*, 1927, vol. xlv., Section B, p. 631.

(The temperature of a bath of molten steel or iron in the reverberatory or blast-furnace may be measured by means of a platinum/platinum-rhodium thermocouple enclosed in a thin quartz tube inside a "silicite" tube; for temperatures up to 1350° C. a nickel-iron couple may also be used. Temperatures taken with a Holborn-Kurlbaum optical pyrometer during casting are approximately 10° lower than those taken with a thermocouple, provided that the bright spots in the metal stream are focused. The temperature of a stream of molten metal usually appears to be lower than that of the metal in the mould after removal of the slag layer, if the measurements are taken with an optical pyrometer; this is probably due to the presence of an oxide skin on the molten stream.)

SECTION IV.—*A Study of Nickel, Nickel-Chromium, and Nickel-Chromium-Molybdenum Steel Ingots.*

Introduction.

In this section the data derived from various representative ingots are given. The method of investigation is identical with that employed for the ingots described in the First Report, so that direct comparison can be made, and the influence of the recorded data concerning mass, analysis, &c., on the characteristics of the ingots considered. Particulars of the ingots studied will be found in Table II. It will be seen that ingots of this class of steel varying in weight from 15 cwt. to 119 tons have been examined. The example numbers given to the ingots follow on from those given to the ingots in the First Report.

TABLE II.—*Details of Alloy Steel Ingots Examined.*

Ex- am- ple.	Description of Ingot.	Weight.	Size.	Kind of Steel.	Returned Typical Analyses. Per Cent.								Mould Used.
					C.	Mn.	Si.	P.	Ni.	Cr.	Mo.	Cu.	
17	Ordinary square chill ingot. Cast through a runner-box	Tons Cwt. 0 15	Top, 12½ in. sq. Bottom, 10½ in. sq. Length in chill, 3 ft. 6¼ in.	Acid O.-H. 3% Ni	0.30 0.31	0.63	0.23	0.042	0.035	3.11	...	...	A
18	Ditto	2 17	Top, 19½ in. sq. Bottom, 16½ in. sq. Length in chill, 4 ft. 8½ in.	Acid O.-H. 3% Ni	0.30 0.31	0.63	0.23	0.042	0.035	3.11	...	...	F
19	Ordinary square chill ingot	2 4	Top, 18 in. sq. Bottom, 14 in. sq. Length in chill, 4 ft. 8 in.	Electric. 4% Ni-Cr	0.29	0.42	0.27	0.016	0.015	4.38	1.41	...	D
20	Ditto	2 4	Top, 18 in. sq. Bottom, 14 in. sq. Length in chill, 4 ft. 8 in.	Electric. 4% Ni-Cr	0.29	0.42	0.27	0.016	0.015	4.38	1.41	...	D
21	Ordinary rect- angular chill ingot	49 0	Top, 70 in. × 43 in. Bottom, 70 in. × 31 in. Length in chill, 100 in.	Acid Siemens O.-H. Ni-Cr	0.395 0.405	0.41	0.155	0.032	0.027	3.31	1.67	...	...
22	Ordinary round chill ingot	50 0	Top, 52½ in. diam. Bottom, 46½ in. Length, 164 in.	Acid Siemens O.-H.	0.405	0.76	0.140	0.034	0.032	0.38	...	0.05	Q
23		119 10	Top, 75 in. across flats. Bottom, 67 in. Length, 180 in.	Acid Siemens O.-H. Ni- Cr-Mo	0.345	0.54	0.157	0.035	0.028	2.48	0.68	0.632	R

The first two ingots, Examples 17 and 18, are of different weight, namely, 15 cwt. (mould *A*, Table I.), and 2 tons 17 cwt. (mould *F*, Table I.); they were cast from the same acid open-hearth heat of nickel steel, and, therefore, apart from the usual features, a direct study of the effect of mass upon heterogeneity may be made. Examples 19 and 20 are two ingots weighing 2 tons 4 cwt. each (mould *D*, Table I.); they were cast in duplicate moulds from the same electric furnace heat of nickel-chromium steel; the second ingot was cast at a lower temperature, but at a much greater speed than the first, thus enabling the influence of the modified condition of casting to be studied. These four ingots represent modern practice in the production of such alloy steels.

Example 21 is a nickel-chromium steel ingot weighing 49 tons, cast in a rectangular mould.

Example 22 is a 50-ton "carbon" steel (cast in mould *Q*, Table I.) containing a little nickel and also a small percentage of copper, the distribution of both of which elements has been studied.

Example 23 is a large nickel-chromium-molybdenum steel ingot weighing 119 tons (cast in mould *R*, Table I.). This has been examined with a view to learning the effect of very large mass on the distribution of the elements present, particularly as regards the molybdenum content.

Examples 17 and 18 ; Nickel Steel Ingots.

These two ingots were cast mainly to provide information as to whether the element nickel segregates, and, if so, to what extent; also, if possible, to determine whether it influences the segregation of carbon, sulphur, and phosphorus. Further, by casting the ingots of two different sizes and from the same heat of steel, the endeavour was made to obtain information on the influence of the size of ingot upon the segregation by more direct comparison than was possible from the ingots of the First Report. The comparison was rendered still more exact by casting the smaller (11-in.) ingot immediately after the larger (18-in.). They were the last two ingots cast from the heat.

The steel was made in the acid open-hearth furnace; the total weight of the heat was 30 tons, and the test ingot analysed :

C.	Mn.	Si.	S.	P.	Ni.
0.30					
0.31	0.63	0.23	0.042	0.035	3.11 per cent.

It was poured from the furnace at a temperature of 1601° to 1637° C., the bulk coming out at 1619° C. After casting the bulk of the heat into ingots at a temperature of 1532° to 1521° C., the 18-in. ingot (57 cwt.) was cast through a runner-box. The temperature of the stream above the runner-box was 1498° , and below it, 1475° C. The rate of pouring through a $1\frac{1}{2}$ -in. nozzle was 0.325 ton per minute.

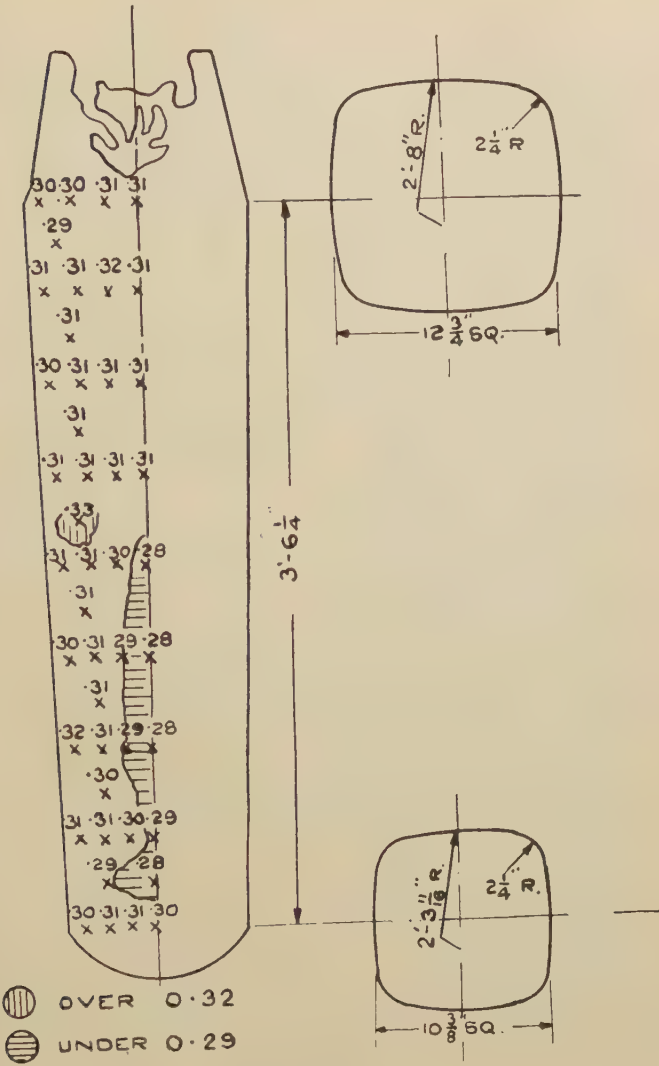
Immediately following, the 11-in. ingot (15 cwt.) was cast, also through a runner-box, at the rate of 0.63 ton per minute, the temperature of the stream being 1475° C.

Examination of Results.—The ingots were sectioned and examined in a manner similar to that adopted for the ingots in the First Report. To bring out in a simple way the character of the segregation in each case in its broad aspect, the zones of highest and lowest percentage, as indicated by the analytical figures, were marked off as shown in the diagrams, by contour lines (see Figs. 20 and 21, *a* to *f*).

The limits of composition chosen for these zones are more or less arbitrary, but are the same in each corresponding case for the larger and smaller ingots. The upper and lower limits are equally above and below, respectively, the average amount of the element as found in the outer zone of the ingot.

The volume and contour of the zones demarked in this way are naturally affected by the ordinary analytical errors. As, however, all the analyses for both the ingots were carried out carefully and in one laboratory, these errors are reduced to a minimum. In any comparison between the two ingots they have still less effect.

The method of contour lines, by assuming uniform gradation of composition between adjacent analysis positions, is also only approximate. These considerations undoubtedly prevent the discussion of these contour diagrams in close detail, but their broader indications only are made use of here, and the conclusions arrived at seem fully justified.



CARBON.

(a)

FIG. 20.—Example 17.

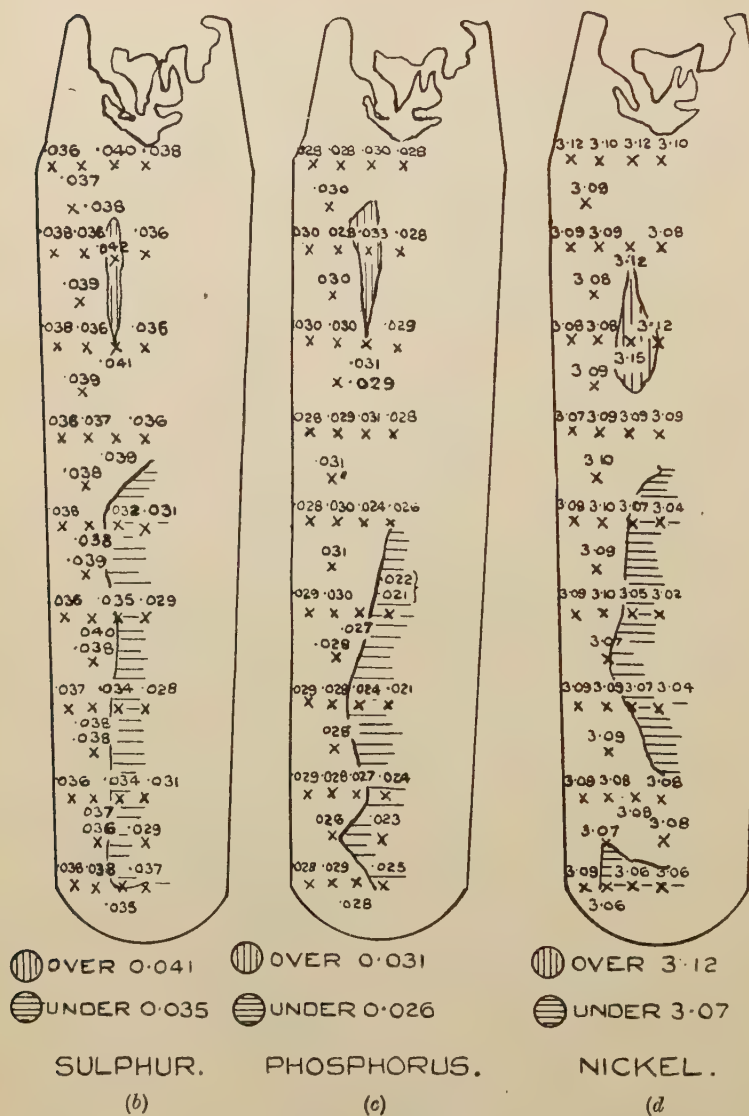


FIG. 20.—Example 17.

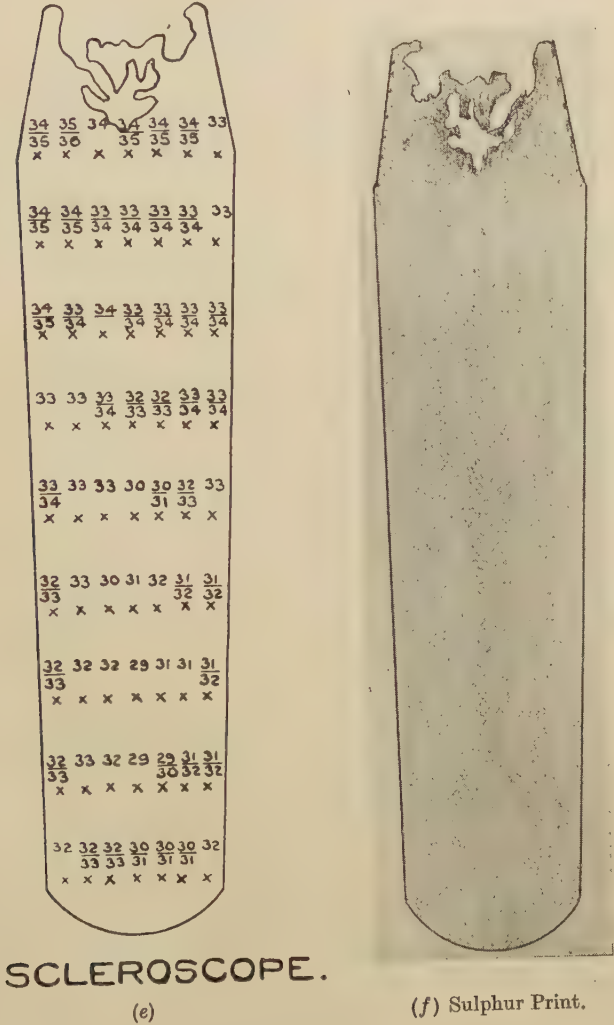
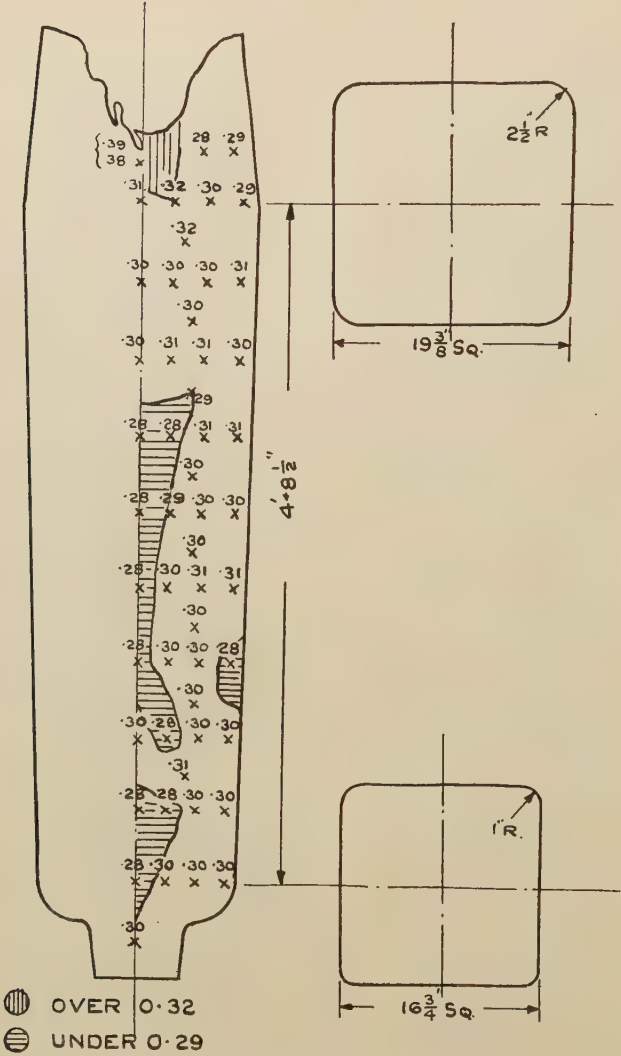


FIG. 20.—Example 17.



CARBON.

(a)

FIG. 21.—Example 18.

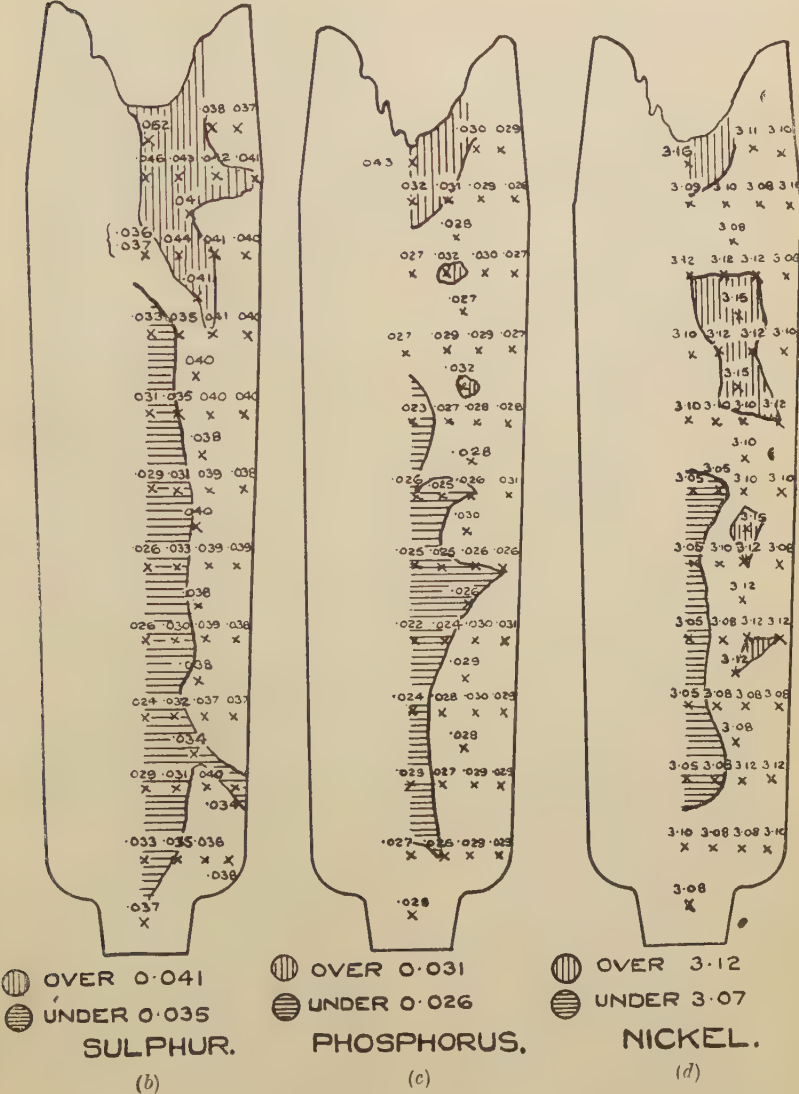
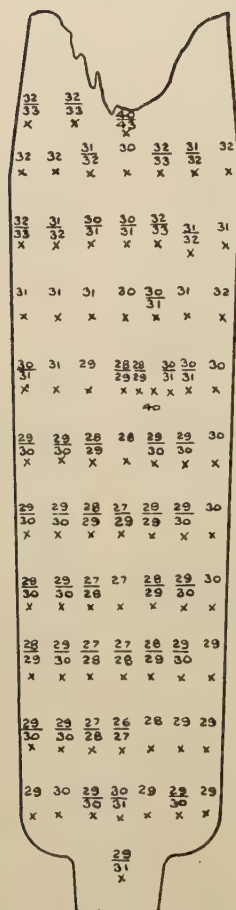
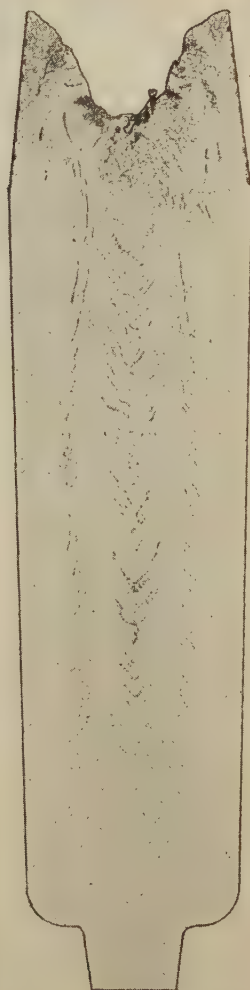


FIG. 21.—Example 18.



SCLEROSCOPE.

(e)



(f) Sulphur Print.

FIG. 21.—Example 18.

Influence of Size of Ingot.—Comparisons of the segregated zones for the 57-cwt. and 15-cwt. ingots show at once a distinctly higher degree of segregation for each of the elements in the former case.

Dealing only with the usable portion of the ingot—that is, below the refractory head—the limits shown by the figures for the different elements are as follows. Notwithstanding the limitations of the method adopted for exploring the variations of composition inside the ingot, referred to in the First Report, these figures do provide some further basis of comparison of the extent of the segregation in the two cases, since the plan of exploration is substantially the same for both. The rather larger number of analyses (49) in the case of the larger ingot, as compared with the smaller (45), may, however, have increased the possibility of obtaining specially high or low figures.

TABLE III.—*Analytical Comparison of Examples 17 and 18.*

Element.	Example 17. 11-in. Ingot.		Example 18. 18-in. Ingot.	
	Highest. %	Lowest. %	Highest. %	Lowest. %
Carbon . . .	0.33	0.28	0.32	0.28
Sulphur . . .	0.042	0.028	0.049	0.024
Phosphorus . .	0.033	0.021	0.032	0.022
Nickel . . .	3.15	3.02	3.16	3.05

While, therefore, as shown by the mapped-out areas, there is clearly a more uneven distribution of the different elements in the larger ingot, there are the same extremes of composition shown by the test samples in both cases, except for sulphur. The more marked segregation of sulphur in the larger ingot is confirmed in the sulphur print.

Segregation of Nickel.—As the above figures show, there is a slight but definite segregation of the nickel, following the same general mode of distribution as the other segregating elements, carbon, sulphur, and phosphorus. This is specially significant because of the question of the chemical relations of nickel with

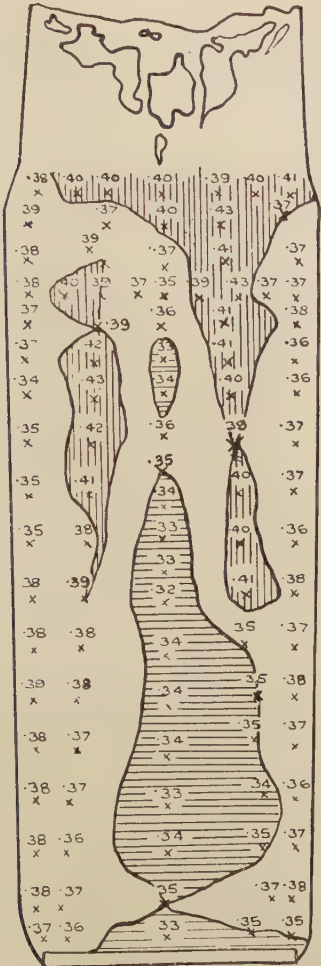
the other elements present. Its degree of segregation is, in fact, comparable with that found for manganese in the carbon steel ingots of the First Report. While, however, manganese combines with carbon and with sulphur, nickel in steel, as far as is known at present, does not combine to any appreciable extent with these other elements, but simply dissolves in the iron. Manganese may, therefore, be expected to take part in the segregation of carbon and sulphur, but not the nickel. The fact of the segregation of nickel, therefore, seems to give support to those theories based on the equilibrium diagram and selective freezing, rather than to those which postulate a floating upwards of segregates. Taking the elements as a whole, both effects may be in operation, but it seems apparent that the effects resulting from the characteristics of the equilibrium diagram have their share. On the other hand, these results may be an indication that nickel does, contrary to the present ideas, associate chemically with one or other of the elements mentioned.

Effect of Nickel on the Segregation of the other Elements.—The remarks made above would seem to imply that nickel would have little effect upon their degree of segregation, as compared with what happens in the absence of nickel.

For definite evidence upon this point, ingots of similar size and composition, and otherwise similar in all respects, but without nickel content, are really necessary. Some sort of approximate comparison is, however, possible between the 57-cwt. ingot and the 55-cwt. ingot, Example 4, of the First Report (Fig. 22, *a* to *e*). The corresponding compositions are as follows :

TABLE IV.—*Comparison of Nickel Steel and Carbon Steel Ingots.*

Ingot.	Weight. Tons. Cwt.	Analysis. Per Cent.						
		C.	Mn.	Si.	S.	P.	Ni.	
Nickel steel	2 17	0.305 0.3035	0.63 ...	0.23 ...	0.042 0.0380	0.035 0.0285	3.11 3.095	Test ingot Outer zone of ingot (average)
Carbon steel	2 15	0.34 0.370	0.72 ...	0.282 ...	0.040 0.0385	0.043 0.0451	Nil Nil	Test ingot Outer zone of ingot (average)



⊖ OVER 0.39
⊙ UNDER 0.35
CARBON.

(a)

FIG. 22.—Example 4.

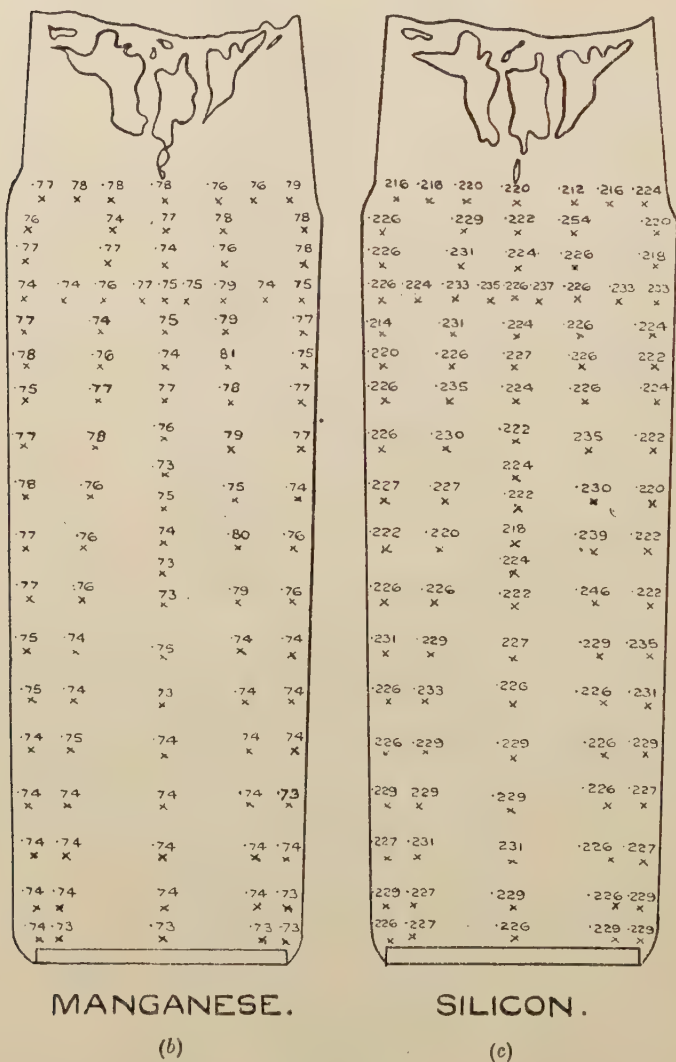


FIG. 22.—Example 4.

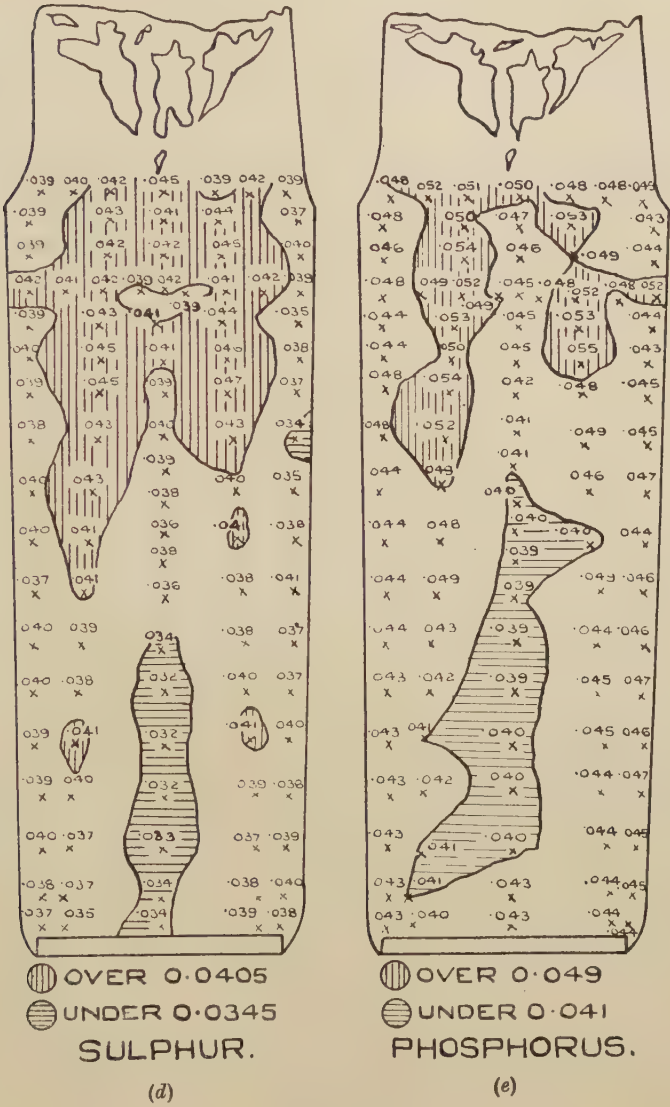


FIG. 22.—Example 4.

The ingots are both of acid Siemens steel, square in the case of the nickel steel, but somewhat rectangular and shorter and heavier in section for the carbon steel. The latter was also cast in a much lighter chill. The casting temperature was, however, similar, namely, 1480° C. There is also a difference in the plan of exploration of the sections for variations in analysis. These differences are sufficient to prevent any definite conclusions as to the influence of nickel, but it was nevertheless thought interesting, in view of the points of similarity, to make the comparison. The figures, obtained in the same way as those above, work out as follows :

TABLE V.—*Comparison of Nickel Steel and Carbon Steel Ingots.*

Element.	Nickel Steel Ingot.		Carbon Steel Ingot.	
	Highest. %	Lowest. %	Highest. %	Lowest. %
Carbon . . .	0·32	0·28	0·43	0·32
Sulphur . . .	0·049	0·024	0·047	0·032
Phosphorus . .	0·032	0·022	0·055	0·039
Nickel . . .	3·16	3·05	Nil	Nil

On these figures, carbon and phosphorus have segregated less in the ingot of nickel steel, but sulphur has done so to a greater extent.

As a basis of further comparison, areas have been mapped out on the diagrams for the carbon steel ingot (Fig. 22) in a similar way to those prepared for the nickel steel ingot (Fig. 21). These show zones of high and low percentage for the various elements, carbon, sulphur, and phosphorus. In view of the differences in average composition of the two ingots shown by Table IV., and for want at present of any more scientific basis of comparison, the limits chosen for these areas have been taken as nearly as possible in proportion to those for the nickel steel ingot, using, as before, the average composition of the outer zones as a basis, on the assumption that they are more directly comparative than the analyses shown by the test ingots.

The segregation of carbon, as shown in this manner, is rather more pronounced in the case of the ingot of plain carbon steel. The average content of sulphur is very similar in the two cases.

The mode of distribution is, however, appreciably different, making comparison difficult. In the case of the carbon steel ingot there is a zone of comparatively low sulphur content, and a large one where the values are high. In the nickel steel ingot the reverse is the case.

As regards phosphorus, of which the average content is appreciably greater for the carbon steel ingot, the degree of segregation in the carbon steel ingot seems greater on the whole than for the nickel steel ingot.

Altogether, and bearing in mind the imperfections in these methods of comparison, and the absence of a definite criterion as to degree of segregation, it does not seem safe to say that nickel has any definite influence on the degree of segregation of the elements carbon, sulphur, and phosphorus.

Incidentally, it is interesting to see how these diagrams, whether for carbon, sulphur, phosphorus, or nickel, and in either carbon steel or nickel steel, indicate in a fairly consistent way the general mode of the segregation in ingots; there is a comparatively pure zone along the axis and towards the bottom of the ingot, and also a zone of the highest concentrations at the top of the ingot, which subdivides lower down, so as to occupy a position between the purer axial zone and the outside surface of the ingot.

Examples 19 and 20 ; Nickel-Chromium Steel Ingots.

Examples 19 and 20 were intentionally prepared from the same electric furnace heat. The cast weighed 8 tons 10 cwt., and four ingots were cast, all in moulds of the same design (see mould *D*, Fig. 4). They were numbered *A*, *B*, *C*, and *D* in the order of teeming; ingot *B* was selected as Example 19 and ingot *D* as Example 20.

At the moment of tapping, the steel and slag analysed as follows:

Steel.		%	Slag.		%
Carbon	.	0.29	SiO ₂	.	20.74
Manganese	.	0.42	FeO	.	2.16
Silicon	.	0.27	Al ₂ O ₃	.	2.24
Sulphur	.	0.016	MnO	.	0.13
Phosphorus	.	0.015	CaO	.	61.42
Nickel	.	4.38	Cr ₂ O ₃	.	...
Chromium	.	1.41	MgO	.	8.14

A reducing slag had operated for some time prior to finishing.

The time taken to pour the steel from the furnace was 2 min. 20 sec. After 2 min. 27 sec. had elapsed, the ingot *A* was teemed over a period of 3 min. 40 sec. with a $\frac{3}{4}$ -in. nozzle. After a lapse of 18 sec., ingot *B* was teemed in 3 min. 40 sec. with a $\frac{3}{4}$ -in. nozzle. 25 sec. later teeming of ingot *C* was commenced, and was finished in 3 min. 55 sec. A special double nozzle was being employed, and the last ingot *D* was therefore teemed, after a lapse of 50 sec., with a 1-in. nozzle over a period of 2 min. 10 sec.

The temperature of the steel during tapping into the ladle was determined as 1595° C. The average temperature during the teeming of ingot *B* was 1590° C., whilst that of ingot *D* was 1550° C. It will thus be seen that ingot *B* was cast much hotter and with a smaller nozzle than ingot *D*, and as these were the only variables in regard to the two ingots, a comparative study is of interest.

Owing to the composition of the steel resulting in pronounced air-hardening characteristics, it was necessary to anneal the ingots before sectioning along the axis, and this was done by heating to 850° C., and then very slowly cooling down in the furnace. The feeder-heads were then removed. After longitudinal sections had been prepared along the axis, exposing the exact central planes of the ingots, the surfaces were ground and polished and then etched with 2 per cent. HNO_3 in water. The macrostructures thus produced lent themselves indifferently to reproduction, so it was decided to reproduce the comparative crystal structures of the two sections. This was done by laboriously tracing from the macrophotographs the boundaries of the primary crystals, with the results shown in Figs. 23, *f* and *g* (Plate XXIV.). It is hoped that this comparative study will throw some light upon the mechanism of freezing. It will be seen that in each ingot there is a well-defined outer layer of the first metal to freeze, consisting of very small crystals. Growing from this layer, in ingot *B* (Fig. 23, *f*), is the region of columnar crystals, which tapers off towards the top of the ingot. These columnar crystals are absent in ingot *D*. Two important central zones occur in both ingots, a zone of uniformly small crystals in the lower portion, and another of very large crystals in the upper portion. In the ingot *D*, cast at the lower temperature, the small crystals extend much higher up the ingot, and the zone of large crystals becomes much smaller, as, indeed, do the crystals themselves. It is

x x x x
C. 0.30 0.35 0.34 0.31
Ni 4.44 4.49 4.39 4.38
Cr 1.34 1.35 1.37 1.36

x x x x
C. 0.29 0.30 0.32 0.32
Ni 4.44 4.48 4.50 4.39
Cr 1.33 1.33 1.35 1.30

x x x x
C. 0.31 0.33 0.32 0.34
Ni 4.47 4.46 4.44 4.46
Cr 1.35 1.32 1.33 1.34

x x x x
C. 0.31 0.32 0.32 0.32
Ni 4.47 4.45 4.40 4.42
Cr 1.33 1.32 1.33 1.34

x x x x
C. 0.29 0.31 0.31 0.28
Ni 4.44 4.43 4.41 4.37
Cr 1.33 1.33 1.34 1.31

x x x x
C. 0.30 0.32 0.30 0.29
Ni 4.46 4.48 4.40 4.51
Cr 1.35 1.32 1.33 1.33

x x x x
C. 0.28 0.32 0.31 0.27
Ni 4.46 4.44 4.38 4.51
Cr 1.33 1.32 1.30 1.30

x x x x
C. 0.30 0.30 0.30 0.27
Ni 4.44 4.41 4.35 4.35
Cr 1.35 1.32 1.31 1.30

x x x x
C. 0.30 0.30 0.30 0.28
Ni 4.45 4.43 4.41 4.36
Cr 1.34 1.32 1.32 1.29

x x x x
C. 0.27 0.29 0.31 0.30
Ni 4.48 4.40 4.38 4.36
Cr 1.30 1.31 1.31 1.31

INGOT B.

(a) Example 19.

x x x x
C. 0.34 0.32 0.31 0.33
Ni 4.40 4.43 4.44 4.44
Cr 1.35 1.33 1.36 1.35

x x x x
C. 0.30 0.32 0.32 0.34
Ni 4.41 4.40 4.44 4.42
Cr 1.34 1.34 1.33 1.36

x x x x
C. 0.31 0.34 0.32 0.29
Ni 4.41 4.40 4.43 4.42
Cr 1.36 1.36 1.35 1.35

x x x x
C. 0.31 0.31 0.29 0.29
Ni 4.42 4.38 4.41 4.36
Cr 1.35 1.32 1.36 1.33

x x x x
C. 0.31 0.31 0.28 0.25
Ni 4.40 4.40 4.36 4.34
Cr 1.33 1.35 1.31 1.29

x x x x
C. 0.31 0.29 0.29 0.27
Ni 4.42 4.38 4.33 4.34
Cr 1.34 1.32 1.31 1.33

x x x x
C. 0.31 0.30 0.27 0.27
Ni 4.42 4.37 4.37 4.33
Cr 1.34 1.35 1.30 1.29

x x x x
C. 0.30 0.30 0.27 0.26
Ni 4.42 4.41 4.37 4.33
Cr 1.33 1.35 1.30 1.27

x x x x
C. 0.30 0.30 0.27 0.26
Ni 4.39 4.38 4.34 4.32
Cr 1.31 1.31 1.31 1.31

x x x x
C. 0.30 0.28 0.28 0.30
Ni 4.35 4.34 4.33 4.34
Cr 1.31 1.31 1.35 1.29

INGOT D.

(b) Example 20.

FIG. 23.

E.		
x		
0.30 C.		
0.42 Mn.		
0.23 Si.		
0.007 S.		
0.015 P.		
4.34 Ni.		
1.32 Cr.		

G.	D.
x	x
0.30	0.30 C.
0.43	0.42 Mn.
0.23	0.23 Si.
0.009	0.008 S.
0.017	0.016 P.
4.40	4.41 Ni.
1.32	1.34 Cr.

A.	F.	C.
x	x	x
0.29	0.31	0.27 C.
0.42	0.42	0.42 Mn.
0.22	0.22	0.21 Si.
0.007	0.009	0.009 S.
0.016	0.016	0.016 P.
4.42	4.39	4.33 Ni.
1.32	1.33	1.31 Cr.

B.		
x		
0.28 C.		
0.40 Mn.		
0.23 Si.		
0.007 S.		
0.017 P.		
4.32 Ni.		
1.30 Cr.		

INGOT B.

(c) Example 19.

E.		
x		
0.33 C.		
0.42 Mn.		
0.22 Si.		
0.008 S.		
0.016 P.		
4.45 Ni.		
1.31 Cr.		

G.	D.
x	x
0.32	0.30 C.
0.44	0.42 Mn.
0.23	0.23 Si.
0.009	0.007 S.
0.017	0.017 P.
4.46	4.40 Ni.
1.34	1.31 Cr.

A.	F.	C.
x	x	x
0.29	0.30	0.25 C.
0.41	0.43	0.41 Mn.
0.19	0.22	0.21 Si.
0.010	0.008	0.006 S.
0.018	0.018	0.013 P.
4.39	4.46	4.33 Ni.
1.33	1.34	1.28 Cr.

B.		
x		
0.26 C.		
0.43 Mn.		
0.21 Si.		
0.006 S.		
0.013 P.		
4.31 Ni.		
1.29 Cr.		

INGOT D.

(d) Example 20.

FIG. 23.

appreciated that the crystals disclosed are probably pseudomorphs of the original crystals. Even the latter statement tends to be controversial, and it is not the intention of the Committee to discuss the theoretical implications of the data here disclosed.

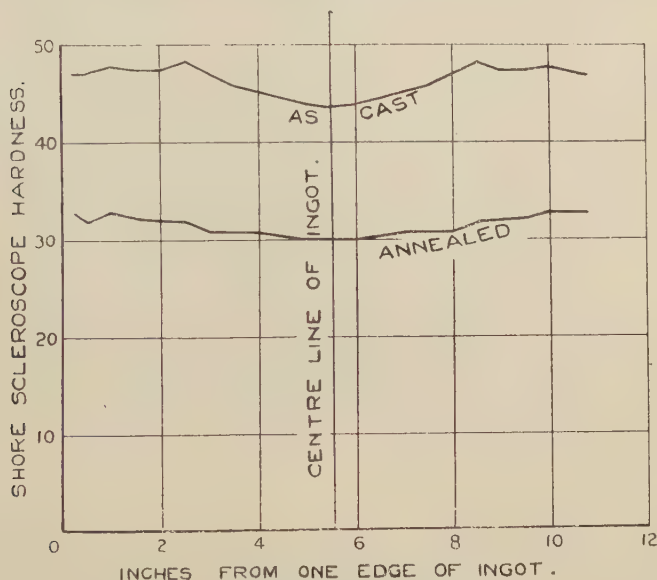


FIG. 23 (e).—Hardness Curve of a 3% Nickel-Chromium Ingot in the As Cast and Annealed Conditions.

It was suggested that the outer shell of small crystals might be due to modifications resulting from the annealing process. Another ingot in the “as cast” state, and of the following analysis, was therefore selected :

	%
Carbon	0.31
Manganese	0.46
Silicon	0.27
Sulphur	0.014
Phosphorus	0.020
Nickel	4.19
Chromium	1.29

The ingot was of square section, 12 in. square at the top of the chill portion, and 10 in. square at the bottom ; it was cast with a refractory-lined feeder-head.

This ingot was fractured cold, as shown in Fig. 23*h* (Plate XXV.).

The fractures *A*, *B*, and *C* are reproduced in Figs. 23, *i*, *k*, and *l*, respectively. Fig. 23*m* (Plate XXVI.) is a large-scale reproduction of a portion of the fracture *B*. It will be seen that the existence of the outer zone of small crystals is confirmed, and that growing from these there is a layer of the columnar crystals, which again tapers off in thickness as the top of the ingot is approached. As a matter of interest, the middle piece of the ingot was used for further study. The upper fracture was ground, and a transverse section of the ingot prepared. This was etched with Heyn's reagent, and the macrostructure is reproduced in Fig. 23*n*; this confirms, but adds little to, the information derived from the fracture. A hardness curve was obtained with a Shore scleroscope.

This piece of ingot was next annealed at a temperature of 650° C., and a transverse fracture obtained from the middle of the piece, shown in Fig. 23*o*. From this it will be seen that it is the primary crystallisation which is still apparently responsible for the form of fracture. A transverse section was then machined in proximity to this fracture, ground and polished, and etched, resulting in the production of the macrostructure reproduced in Fig. 23*p*. A hardness curve was again obtained, and the comparative figures for the "as cast" and "annealed" conditions are plotted in Fig. 23*e*.

Reverting to the Examples 19 and 20, these were analysed in the manner generally adopted by the Committee, with the results given in Figs. 23, *a*, *b*, *c*, and *d*.

Example 21 ; Nickel-Chromium Steel Ingot.

The weight of this nickel-chromium steel ingot was 49 tons ; its size was 70 in. \times 43 in. at the top, 70 in. \times 31 in. at the bottom, and length, excluding head, 100 in. (see Fig. 24*h*). The steel was made in the acid open-hearth and was top-poured into a chill mould. The distribution of the elements, as revealed by analysis on drill samples, is shown in Figs. 24, *a* to *g*, and a sulphur print appears in Fig. 24*i* (Plate XXVII.). It will be seen that in this ingot the general segregation phenomena are similar to those in plain carbon steels. Maximum segregation is found in the upper part of the ingot near the central axis. Except in the case of silicon, negative segregation is found in the lower portion of the ingot.



(f) Example 10.



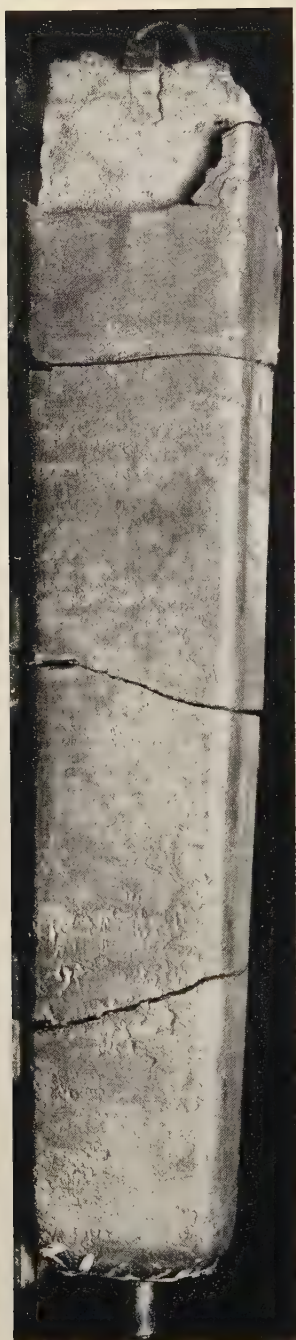
(g) Example 20.

FIG. 43. Macrographic structures.

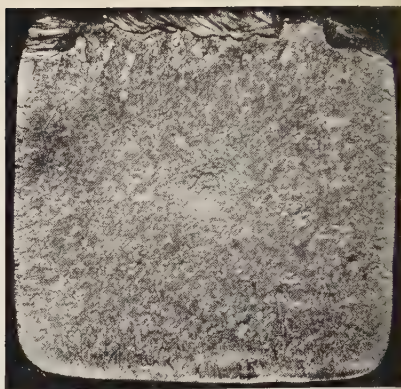
A

B

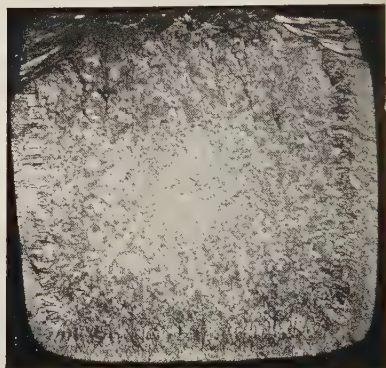
C



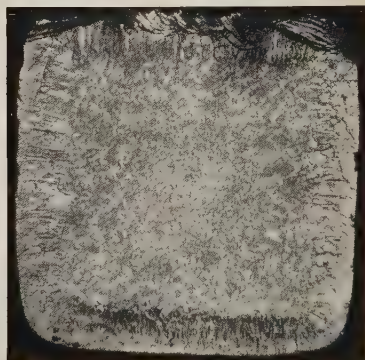
(h) The ingot after fracturing cold.



(i) Macrostructure of fracture A in Fig. 23 (h).



(k) Macrostructure of fracture B in Fig 23 (h).

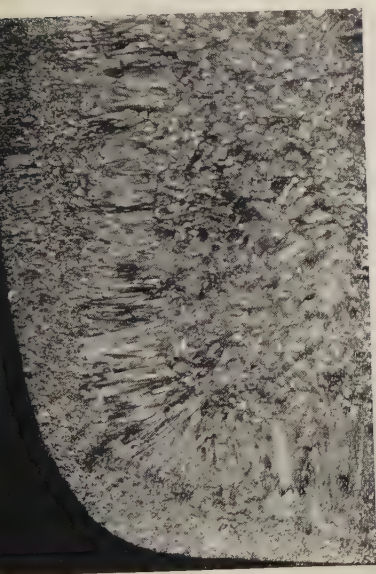


(l) Macrostructure of fracture C in Fig 23 (h).

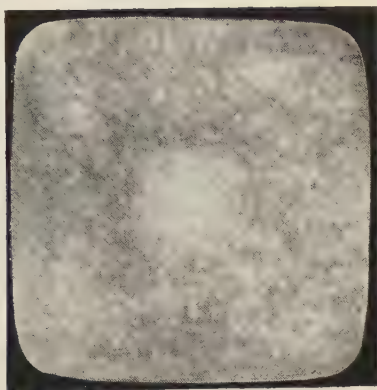
FIG. 23 (h), (i), (k), (l).—A 3 per cent. nickel-chromium ingot.



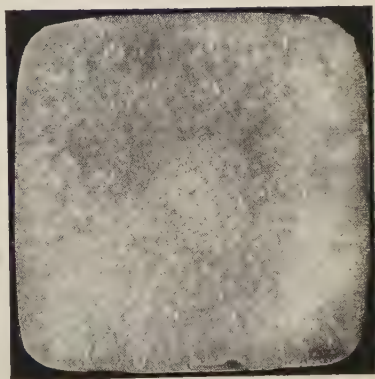
(m) Part of fracture *B* (Fig. 23 (*h*)) to larger scale.



(p) Macrostructure of middle portion of ingot after annealing at 650°C.



(n) Macrostructure of middle portion of ingot as cast (Fig. 23 (*h*)).



(b) Macrostructure of transverse section near section in Fig. 23 (*o*).

FIG. 23 (*m*), (*n*), (*o*), (*p*).—A 3 per cent. nickel-chromium ingot.



(i) Sulphur print.

FIG. 24.—Example 21.

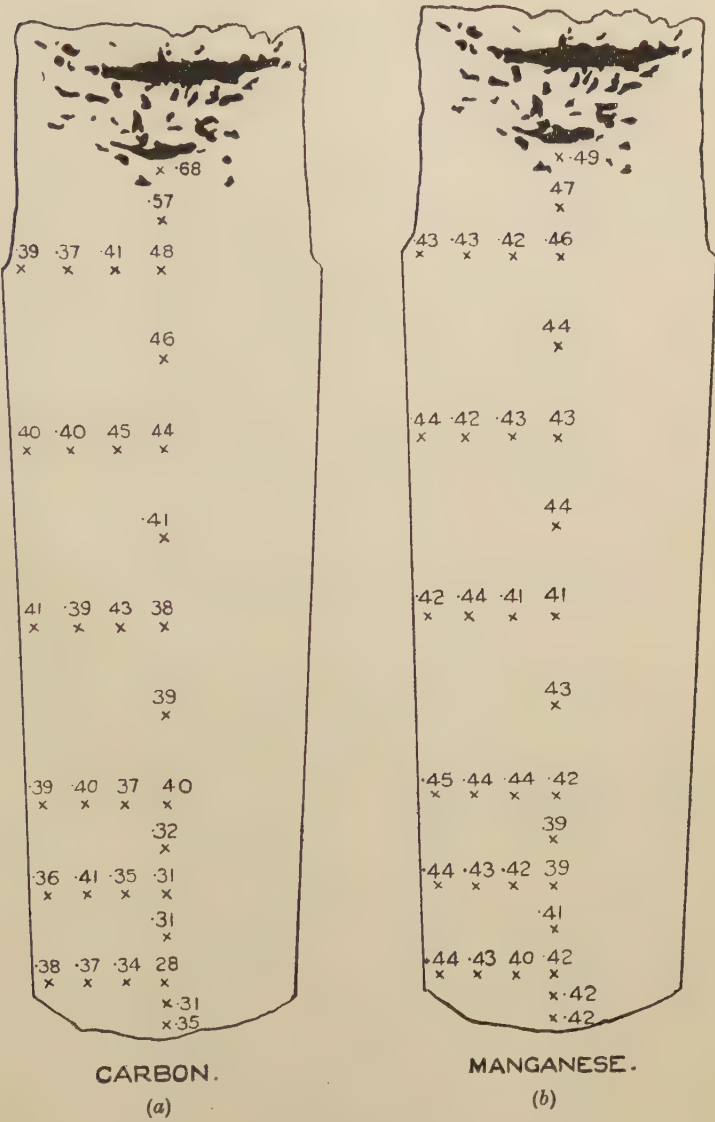


FIG. 24.—Example 21.

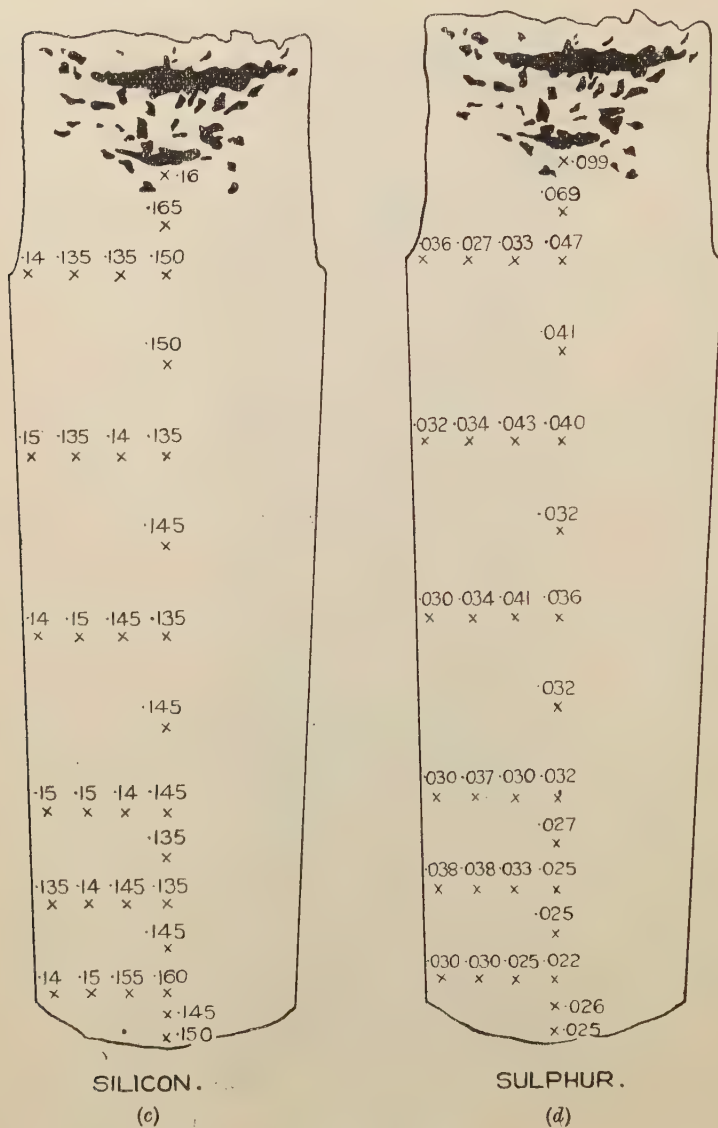


FIG. 24.—Example 21.

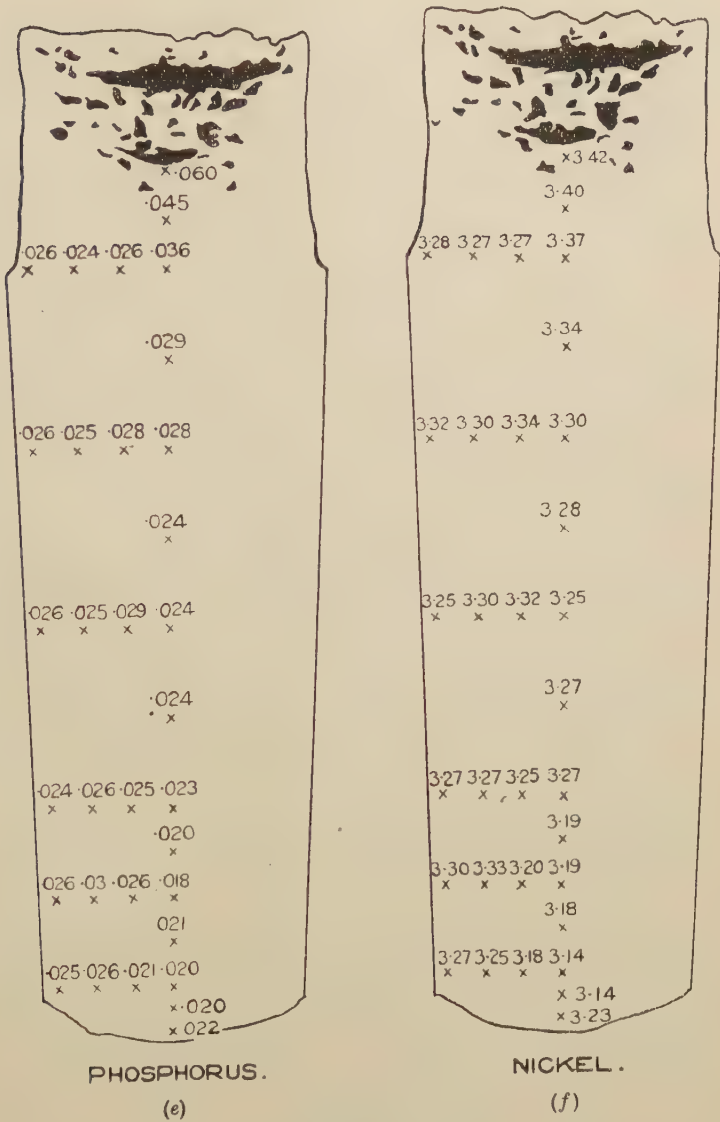


FIG. 24.—Example 21.

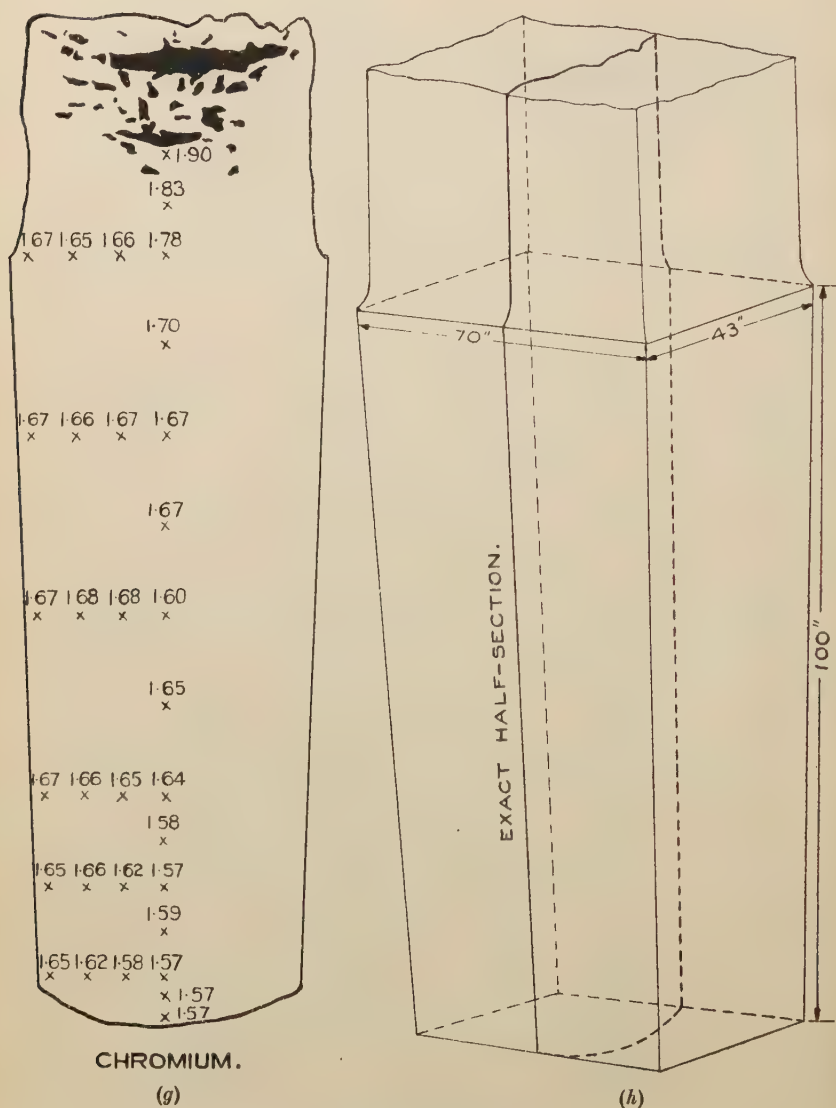


FIG. 24.—Example 21.

Silicon shows positive segregation in this region. Compared with Examples 12 and 14 of the First Report, it would appear that the addition of nickel and chromium has but very little effect on the amount of segregation, as revealed by the analyses. There is, however, an indication that there is a slight reduction in the segregation of carbon, sulphur, and phosphorus. Nickel segregates to only a small extent. Chromium shows large segregation immediately below the cavity, but there is only a very small variation throughout the body of the ingot itself.

*Example 22 ; Ingot containing Small Percentages of
Nickel and Copper.*

This was an ingot of low-nickel steel, containing a small percentage of copper. Its size was $52\frac{1}{2}$ in. diam. at the top, $46\frac{1}{2}$ in. at the bottom, and 164 in. in length excluding the head. Its weight was 50 tons.

Figs. 25, *a* to *g*, show the result of analyses at various positions in the ingot. In this case also the general segregation phenomena are similar to those in plain carbon steel ingots, and are of the same order. There is, however, no indication of positive segregation of the silicon in the lower portion of the ingot. Nickel again is very uniform throughout the ingot, and does not appear to segregate to any marked extent. Only a small amount of copper is present, and little can be deduced from the results as to whether this element segregates appreciably or not.

Example 23 ; Nickel-Chromium-Molybdenum Steel Ingot.

The weight of this ingot was 119 tons, and its size 75 in. across the flats at the top, 67 in. at the bottom, and 180 in. in length excluding the head.

The whole of the ingot was not subject to analysis, as in the previous cases ; Figs. 26, *a* to *g*, give the analyses at the various points tested. The few analyses obtained, however, serve to indicate that the segregation of carbon, sulphur, and phosphorus is not materially affected by the alloying elements in this size of ingot. Even in this ingot the maximum variation of nickel is only about 5 per cent. of the mean analysis. Chromium, on the other hand, shows a variation of 30 per cent. Molybdenum also segregates to a marked extent, and shows a range of composition of 70 per cent.

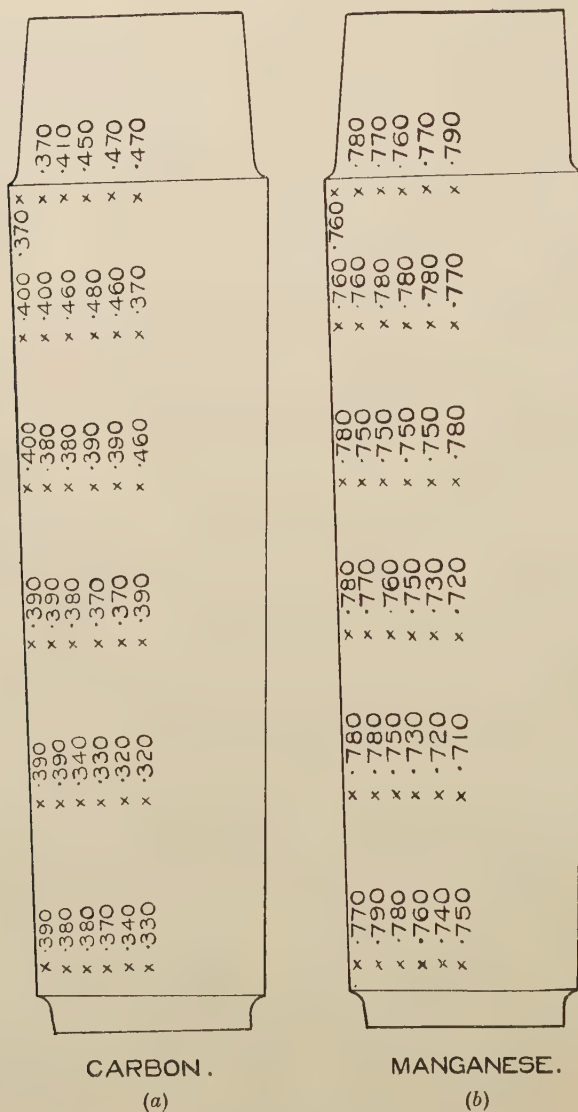


FIG. 25.—Example 22.

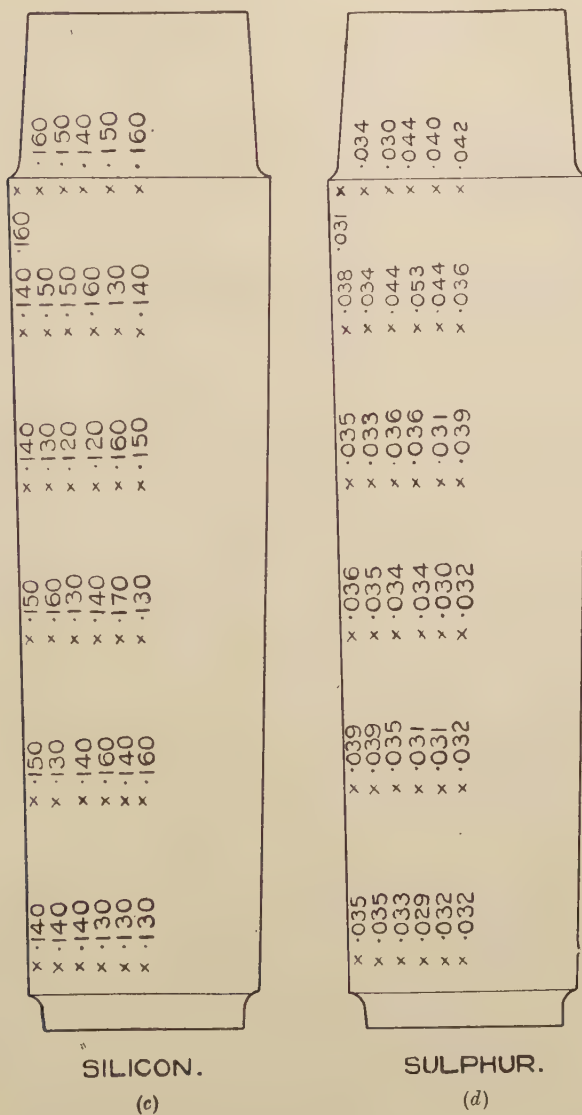


FIG. 25.—Example 22.

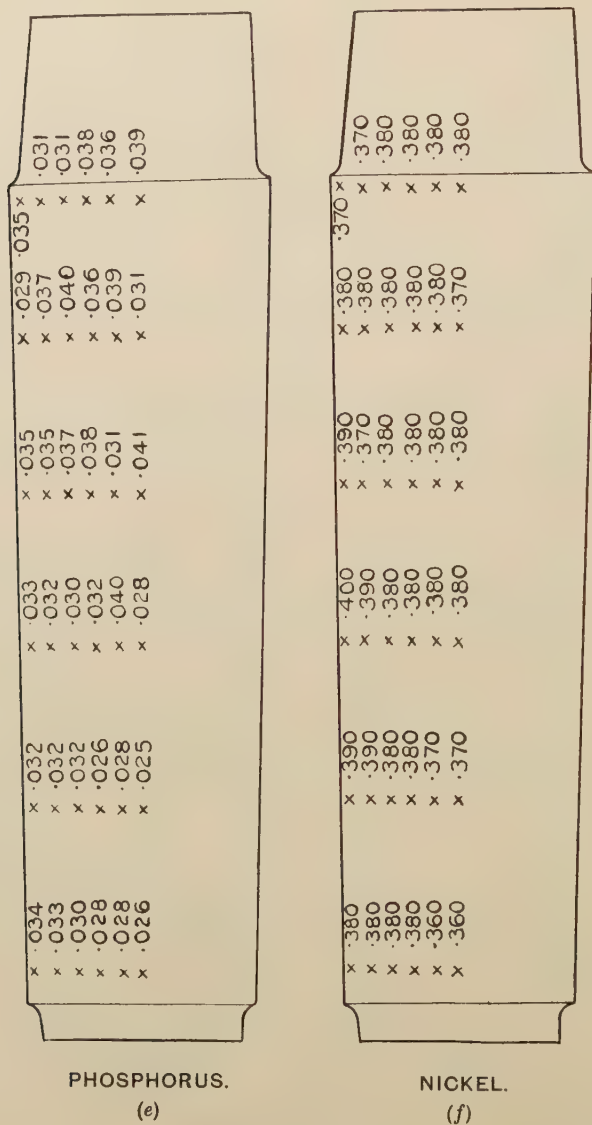
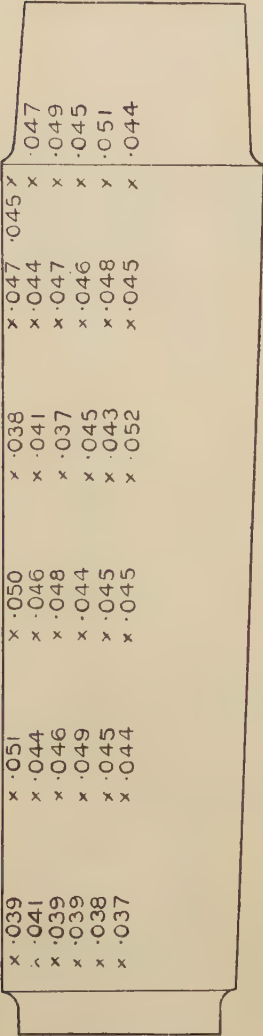
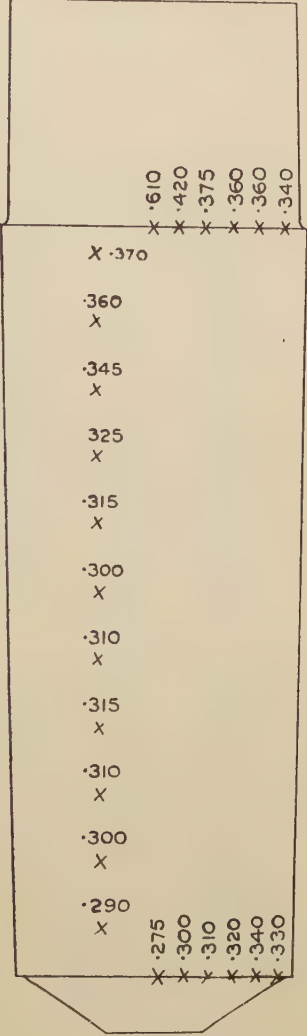


FIG. 25.—Example 22.



COPPER.
(g)

FIG. 25.—Example 22.



CARBON
(a)

FIG. 26.—Example 23.

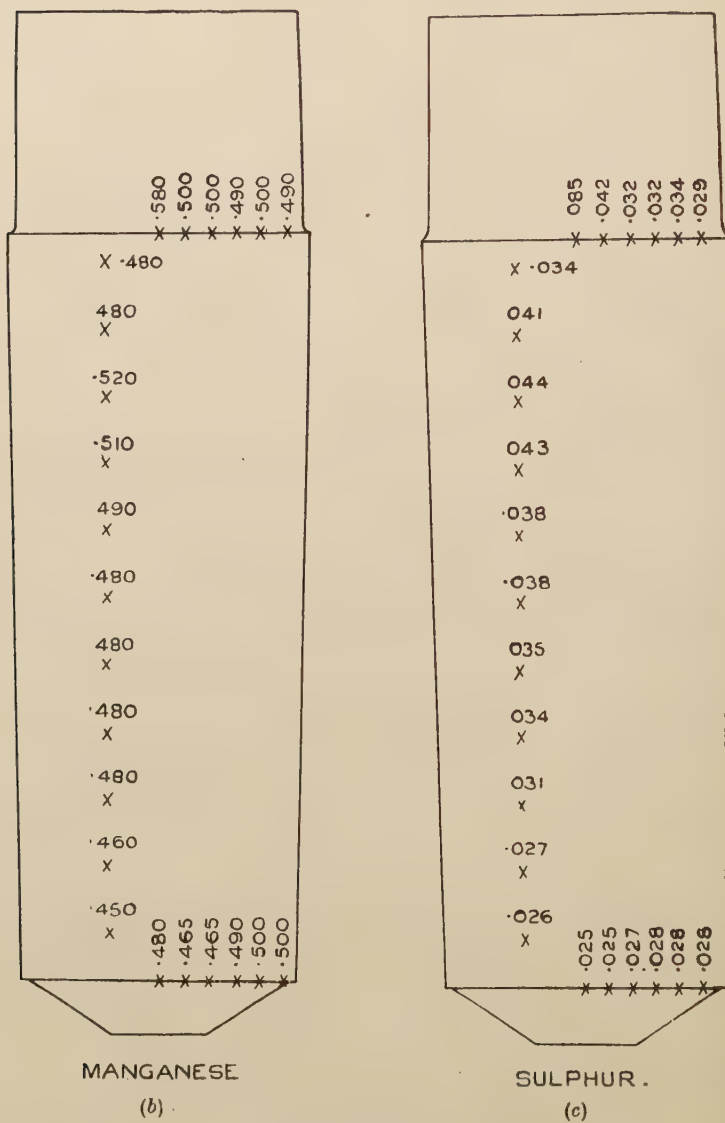


FIG. 26.—Example 23.

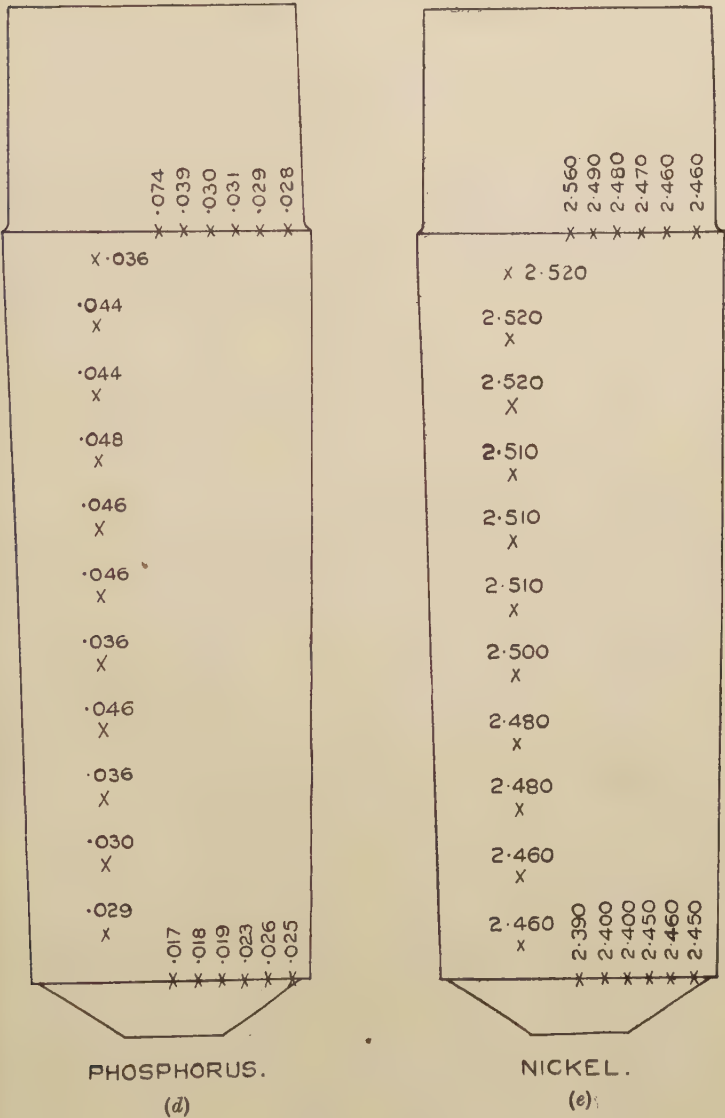


FIG. 26.—Example 23.

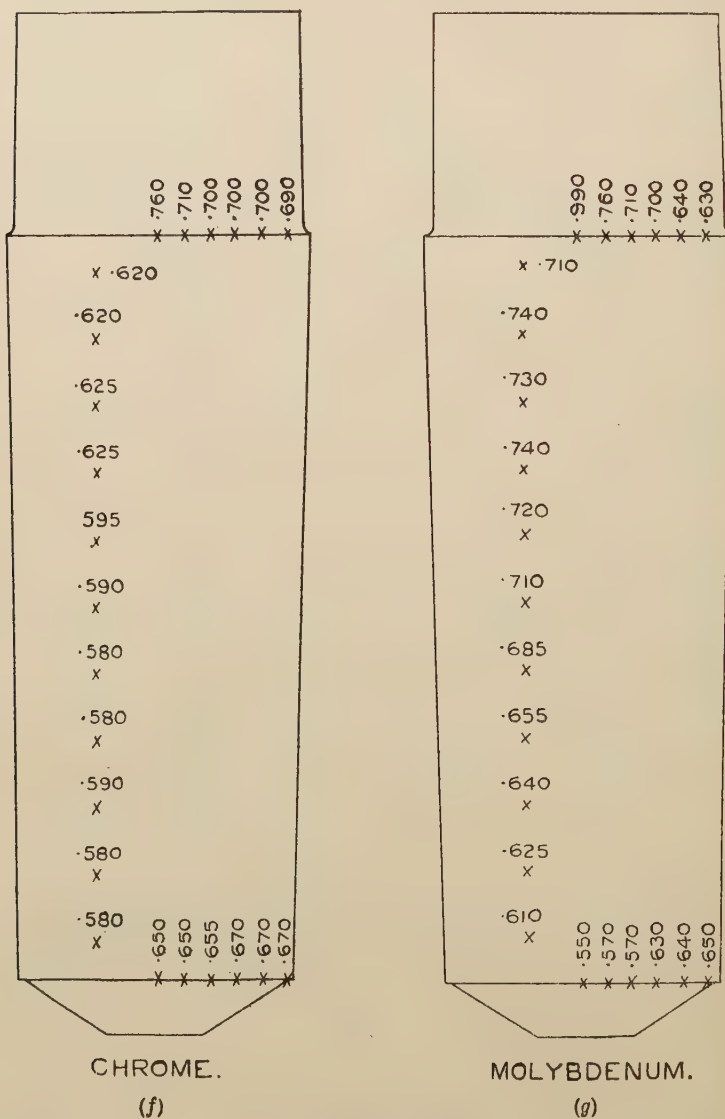


FIG. 26.—Example 23.

General Considerations.

In the First Report, comparisons between the different ingots, as regards variations in composition, were facilitated by arbitrarily selecting the same seven approximate positions in the section of each ingot. A diagram illustrating these positions was given in Fig. 5 of the First Report¹; the same positions, *A, B, C, D, E, F,* and *G,* will be found marked in Figs. 23, *c* and *d.* By recording the content of each element at these different positions, the values recorded in Tables VI. to XIV. were obtained.

TABLE VI.—*Carbon.*

Example.	Position.							
	<i>A.</i>	<i>B.</i>	<i>C.</i>	<i>D.</i>	<i>E.</i>	<i>F.</i>	<i>G.</i>	<i>X.</i> ²
	%	%	%	%	%	%	%	%
17	0.30	0.285	0.28	0.31	...	0.30	0.31	0.30
18	0.31	0.30	0.28	0.29	...	0.31	0.29	0.30
19	0.29	0.28	0.27	0.30	...	0.31	0.30	0.29
20	0.29	0.26	0.25	0.30	...	0.30	0.32	0.29
21	0.41	0.32	0.38	0.45	0.57	0.41	0.42	0.40
22	0.39	0.32	0.39	0.41	0.47	0.37	0.45	(0.39)
23	...	...	...	...	0.61	0.31	0.32	0.345

TABLE VII.—*Manganese.*

Example.	Position.							
	<i>A.</i>	<i>B.</i>	<i>C.</i>	<i>D.</i>	<i>E.</i>	<i>F.</i>	<i>G.</i>	<i>X.</i> ²
	%	%	%	%	%	%	%	%
17	...	...	...	...	...	...	...	0.63
18	...	...	...	...	...	...	...	0.63
19	0.42	0.40	0.42	0.42	...	0.42	0.43	0.42
20	0.41	0.43	0.41	0.42	...	0.43	0.44	0.42
21	0.42	0.39	0.41	0.43	0.49	0.42	0.42	0.41
22	0.78	0.71	0.72	0.77	0.79	0.75	0.77	(0.78)
23	...	...	...	...	0.58	0.48	0.51	0.54

¹ *Journal of the Iron and Steel Institute*, 1926, No. I. p. 91.

² *X* is the assumed mean composition of the cast as determined by pit sample or other means.

TABLE VIII.—*Silicon.*

Example.	Position.							
	A.	B.	C.	D.	E.	F.	G.	X. ¹
	%	%	%	%	%	%	%	%
17	...	...	...	...	...	...	...	0.23
18	...	...	...	...	...	...	...	0.23
19	0.22	0.23	0.21	0.23	...	0.22	0.23	0.27
20	0.19	0.21	0.21	0.23	...	0.22	0.23	0.27
21	0.14	0.135	0.135	0.14	0.165	0.15	0.14	0.155
22	0.15	0.16	0.13	0.145	0.16	0.135	0.14	(0.15)
23	...	...	...	...	...	...	...	0.157

TABLE IX.—*Sulphur.*

Example.	Position.							
	A.	B.	C.	D.	E.	F.	G.	X. ¹
	%	%	%	%	%	%	%	%
17	0.038	0.030	0.029	0.037	...	0.037	0.039	0.042
18	0.039	0.024	0.026	0.032	...	0.036	0.040	0.042
19	0.007	0.007	0.009	0.008	...	0.009	0.009	0.016
20	0.010	0.006	0.006	0.007	...	0.008	0.009	0.016
21	0.030	0.027	0.036	0.040	0.069	0.037	0.038	0.032
22	0.036	0.032	0.032	0.037	0.042	0.034	0.042	(0.036)
23	...	...	...	...	0.085	0.035	0.043	0.035

TABLE X.—*Phosphorus.*

Example.	Position.							
	A.	B.	C.	D.	E.	F.	G.	X. ¹
	%	%	%	%	%	%	%	%
17	0.029	0.023	0.022	0.028	...	0.030	0.029	0.035
18	0.026	0.024	0.025	0.025	...	0.0255	0.032	0.035
19	0.016	0.017	0.016	0.016	...	0.016	0.017	0.015
20	0.018	0.013	0.013	0.017	...	0.018	0.017	0.015
21	0.026	0.020	0.024	0.028	0.045	0.027	0.027	0.027
22	0.033	0.025	0.028	0.046	0.039	0.031	0.037	(0.033)
23	...	...	...	...	0.074	0.036	0.048	0.028

¹ X is the assumed mean composition of the cast as determined by pit sample or other means.

TABLE XI.—*Nickel*.

Example,	Position.							
	A.	B.	C.	D.	E.	F.	G.	X. ¹
	%	%	%	%	%	%	%	%
17	3·09	3·06	3·02	3·10	...	3·08	3·09	3·11
18	3·08	3·05	3·05	3·10	...	3·11	3·15	3·11
19	4·42	4·32	4·33	4·41	...	4·39	4·40	4·38
20	4·39	4·31	4·33	4·40	...	4·46	4·46	4·38
21	3·25	3·19	3·25	3·32	3·40	3·31	3·32	3·31
22	0·40	0·37	0·38	0·375	0·38	0·38	0·38	(0·40)
23	...	...	...	...	2·56	2·50	2·51	2·48

TABLE XII.—*Chromium*.

Example,	Position.							
	A.	B.	C.	D.	E.	F.	G.	X. ¹
	%	%	%	%	%	%	%	%
19	1·32	1·30	1·31	1·34	...	1·33	1·32	1·41
20	1·33	1·29	1·28	1·31	...	1·34	1·34	1·41
21	1·67	1·58	1·60	1·68	1·83	1·68	1·66	1·67
23	...	...	...	...	0·76	0·58	0·625	0·68

¹ X is the assumed mean composition of the cast as determined by pit sample or other means.

As regards the elements carbon, sulphur, and phosphorus, it would appear that the percentage variations in the different parts of the ingots increase as the size of the ingot increases. It has been mentioned earlier in this section that the presence of nickel and chromium apparently tends to diminish the tendency to segregate. The results for silicon and manganese seem to parallel those obtained on the carbon steel ingots in the First Report. The degree of segregation of nickel is of the same order as that of manganese in plain carbon steels. Whilst manganese combines with sulphur, and to some extent with carbon, yet the large proportion of manganese present is merely in solution. Similarly nickel, which does not form compounds with the other elements, is in simple solution in the iron. The iron-manganese and iron-nickel equilibrium diagrams, for the small percentages concerned,

are of the simple solid solution type, with but a small gap between the solidus and liquidus. For these reasons, the segregation of nickel would be inferred to be of a minor character, as is shown by the data given. The chromium would certainly appear to segre-

TABLE XIII.—*Molybdenum.*

Example.	Position.							
	A.	B.	C.	D.	E.	F.	G.	X, ¹
23	% ...	% ...	% ...	% ...	% 0·99	% 0·685	% 0·74	% 0·632

TABLE XIV.—*Copper.*

Example.	Position.							
	A.	B.	C.	D.	E.	F.	G.	X, ¹
22	% 0·050	% 0·044	% 0·045	% 0·049	% 0·044	% 0·046	% 0·044	% ...

¹ X is the assumed mean composition of the cast as determined by pit sample or other means.

gate to a minor degree. The one study relating to molybdenum indicates a definite tendency to segregate in conformity with the tendencies of the other segregating elements. The examination of the distribution of the small percentage of copper in Example 22 must be regarded as inconclusive, although the analyses indicate a uniform distribution when allowances are made for the difficulties of analysis.

When comparing the results of the figures given by Examples 17 and 18, it should be borne in mind that these ingots were teemed at a low temperature at the end of a heat, that Example 17 was teemed very slowly, and that Example 18 was teemed much more quickly. Again, with regard to Examples 19 and 20, Example 19 was teemed much hotter and less quickly than Example 20. The introduction of the two variables in these pairs

of ingots is explained by the necessity of teeming the cooler steel more quickly.

The average compositions of the representative ingots, as shown by the analysis of drilled samples at the selected positions, have been determined, and are recorded in Table XV. The figures for the various elements are expressed as percentages of the amounts of all the elements as ascertained by analysis of the corresponding

TABLE XV.—*Average Figures for all the Ingots.*

Position in the Ingot.	C.	Mn.	Si.	S.	P.	Ni.	Cr.
<i>E</i>	...	...	...	...	...	...	...
<i>G</i>	106.2	101.5	87.5	96.1	99.4	100.5	96.4
<i>D</i>	104.6	100.5	88.1	87.4	100.0	100.1	96.4
<i>F</i>	101.6	99.5	85.7	87.4	92.2	100.2	96.8
<i>A</i>	101.0	100.0	82.8	86.9	91.1	99.6	96.2
Amount of the element contained in the test ingot	100	100	100	100	100	100	100
<i>C</i>	93.9	96.5	81.0	75.0	79.9	98.3	93.3
<i>B</i>	89.5	95.0	87.0	68.4	76.2	97.8	92.9

test ingot. The ingots included in this table are Examples 17, 18, 19, 20, 21, and 22. Information concerning manganese and silicon is not available for Examples 17 and 18; the data for chromium are confined to Examples 19, 20, and 21.

In Table XVI., which will be found on the following page, the analytical data concerning the various ingots have been tabulated. They have been arranged in such a way as to show the ranges of composition of the ingots as indicated by the analyses of drilled samples taken from each ingot.

TABLE XVI.—*Range of Composition in each of the Representative Ingots as obtained by Analysis of Drilled Samples at the Positions indicated in Figs. 23, c and d.*

In preparing this table, the data for position *E*, which is in the discarded portion of the ingot, have been excluded. The figure for range per cent. for each ingot and element is expressed as a percentage of the amount of the element as ascertained by analysis of the corresponding test ingot.

Example.	Weight of Ingot.	Carbon.			Manganese.			Silicon.			Sulphur.		
		Test Ingot.	Max.	Min.	Range. %	Test Ingot.	Max.	Min.	Range. %	Test Ingot.	Max.	Min.	Range. %
	Tons Cwt.												
17	0 15	0.30	0.31	0.28	10	0.63	...	...	...	0.23	0.23	0.039	24
18	2 17	0.30	0.31	0.28	10	0.63	...	...	...	0.23	0.23	0.042	38
19	2 2	0.29	0.31	0.27	14	0.42	0.43	0.40	7	0.27	0.23	0.042	38
20	2 2	0.29	0.32	0.25	24	0.42	0.44	0.41	7	0.27	0.23	0.016	12
21	49 0	0.40	0.45	0.32	33	0.41	0.43	0.39	10	0.155	0.13	0.010	25
22 ¹	50 0	(0.39)	0.45	0.32	33	(0.78)	0.78	0.71	9	(0.15)	0.16	0.032	41
												0.042	28

Example.	Phosphorus.			Nickel.			Chromium.		
	Test Ingot.	Max.	Min.	Range. %	Test Ingot.	Max.	Min.	Range. %	Test Ingot.
17	0.035	0.030	0.022	23	3.11	3.10	3.02	2.5	...
18	0.035	0.032	0.024	23	3.11	3.15	3.05	3.0	...
19	0.015	0.017	0.016	7	4.88	4.42	4.32	2.0	1.41
20	0.015	0.018	0.013	33	4.88	4.46	4.31	3.5	1.41
21	0.027	0.028	0.020	30	3.31	3.32	3.19	4.0	1.67
22 ¹	(0.033)	0.046	0.025	64	(0.40)	0.40	0.37	7.5	...

¹ In the absence of test ingot analyses, the analyses at position *A* have been taken instead.

SECTION V.—*A Study of Carbon Steel Ingots other than "Killed."**Introduction.*

In the First Report, sixteen carbon steel ingots were studied which had been produced from fully "killed" or piping steel; in Section IV. of this Report, seven alloy steel ingots, cast from the same type of steel, have been considered. In this Section V. a study is presented mainly of ingots belonging to another type of steel, representative of the great tonnage of steel produced for plates, sections, and other general purposes, and which is chiefly characterised by the facts that the steels possess a low carbon content, a low silicon content, and are cast in moulds which are not provided with feeder-heads. During freezing there is a liberation of gas which results in the production of blowholes in certain zones of the ingot, and it was the influence of this factor in modifying the degree and form of the heterogeneity to be found in these ingots which led the Committee to study such material. Owing to the absence of the central shrinkage cavity, and the fact that the small blowholes in this class of material may weld up during the rolling process, a much higher yield of marketable material is produced. It is now believed that all steel, in its process of manufacture in the liquid state, becomes charged, to a greater or less degree, with oxide of iron and gases, and that these must be reduced in quantity to such a degree as is compatible with the service demanded from the steel in the finished state.

The ingots described in the First Report, and in the previous section of the present Report, represent a fair picture of the success which can be attained when the greatest precautions are taken to deoxidise and reduce the gas content to a minimum. Such precautions are essential in the production of ingots of steel required for the most severe conditions of service. On the other hand, for the more common purposes, it is neither necessary, nor is it economically practicable, to carry out the process of de-oxidation and degasification to such a marked degree. In actual practice it is sometimes found desirable, in order to produce certain qualities in the finished product, to cast the steel while it is

highly charged with gas. In other cases it is necessary, mainly for economic reasons, to cast the steel in a partially "killed" state, regulating the casting conditions so that the gases released during freezing, and the variations of composition produced, yield a steel with properties within the limits found to be necessary by practical experience.

It is by these methods of manufacture that the enormous quantities of steel required for plates and sections used in structural work are produced, and in this section are depicted the structures of some typical ingots and the variations of composition which occur.

In Table XVII. will be found the general particulars concerning the ingots dealt with. The data from Examples 24, 25, 26, 27, 28, 30, and 31 are presented as representative of this class of material. Examples 24 and 26 present features very different from those of an ingot of completely "killed" steel. These ingots represent steel cast in such a condition that the ingot contains blowholes, and they show the very marked effect produced by the gas liberated during freezing, while Examples 27 and 25 are in descending order of gas evolution. In the manufacture of steel such as Examples 24 and 25, it is essential that the liquid metal shall evolve large amounts of gas. This is attained: (1) by working with a particular kind of slag, and (2) by making no addition of the "killing" agents, silicon and aluminium.

The data from Example 29 are presented on account of the particular interest of the effect of the high sulphur and phosphorus contents. In the manufacture of this steel very little silicon is added, and yet the ingot shows none of the characteristics of "wild" steel. The additions of sulphur exercise a killing effect, which minimises the liberation of gas, and produces an ingot with the usual features of a "solid" or piping steel ingot. For this reason the steel is cast in moulds with the wide end up and with a feeder-head.

The study of Example 32 is included in this section as illustrating the effect of the practice of casting piping steel in the old type of mould, which produced an ingot heavier in section at the bottom than at the top, and which was not provided with any suitable refractory-lined feeder-head for preventing the formation of pipe in the body of the ingot.

TABLE XVII.—*Details of Carbon Steel Ingots.*

Example.	Description of Ingot.	Weight.	Size.	Kind of Steel.	Analyses, Per Cent.				Mould.	
					C.	Mn.	Si.	S.		P.
24	Rectangular .	Tons. Cwt. 3 1	Top, 23½ in. × 17½ in. Bottom, 21 in. × 15 in. Length, 4 ft. 11¼ in.	Basic Siemens tube steel	0.064	0.35	0.012	0.039	0.01	G ¹
25	Rectangular .	6 15	Top, 2 ft. 9½ in. × 1 ft. 9¾ in. Bottom, 3 ft. 1 in. × 2 ft. 0¾ in. Length, 6 ft. 3 in.	Acid Siemens plate steel	0.10	0.49	0.012	0.037	0.036	J
26	Rectangular .	7 15	Top, 3 ft. 3½ in. × 1 ft. 10½ in. Bottom, 3 ft. 7 in. × 2 ft. 0 in. Length, 6 ft. 5½ in.	Acid Siemens plate steel	0.14	0.52	0.024	0.039	0.024	K
27	Rectangular .	6 15	Top, 2 ft. 9½ in. × 1 ft. 9¾ in. Bottom, 3 ft. 1 in. × 2 ft. 0¾ in. Length, 6 ft. 3 in.	Acid Siemens plate steel	0.13	0.48	0.02	0.039	0.024	J
28	Rectangular .	8 0	3 ft. 4 in. × 2 ft. 1 in. parallel. L., 6 ft. 9 in.	Acid open - hearth plate steel	0.15	0.49	...	0.059	0.061	M
29	Square, with feeder-head	3 6	21 in. sq. at shoulder; 19 in. sq. at base; length, 5 ft. 6 in. in chill.	Basic free-cutting steel	0.12	0.66	0.03	0.113	0.098	I
30	Rectangular .	7 14	(Top, 2 ft. 10 in. × 2 ft. Bottom, 3 ft. × 2 ft. 2 in. Length, 6 ft. 6 in.)	Plate steel	0.19	0.51	0.075	0.041	0.042	L
31	Rectangular .	7 14	10½ in. across flats at top; 14½ in. across flats at bottom; length, 5 ft. 10½ in.	Plate steel	0.13	0.50	...	0.033	0.020	L
32	Bottom cast octagonal	1 3½		Acid Siemens	0.63	0.66	0.21	0.048	0.044	B

¹ Without feeder-top.

Example 24; Tube Steel Ingot.

This ingot is made of steel of the rimming type; it left the launder at 1635° C., and is the kind used for tube manufacture by the Pilger process. The data given are analyses, Figs. 27, *a* to *e*, and sulphur print and nitric acid etching print, Figs. 27, *f* and *g* (Plate XXVIII.). Details of the mould (*G*) are given in Fig. 7.

Examination of Sulphur Print and Nitric Etching Print.—Four zones may be distinguished :

Zone 1 : A thin solid outer shell about $\frac{1}{2}$ in. thick.

Zone 2 : A zone about 4 in. thick all round the ingot, free from segregation, but containing numerous elongated blowholes, especially in the bottom half of the ingot. These holes are free from segregate.

Zone 3 : A thin envelope of highly segregated material containing numerous blowholes of globular form.

Zone 4 : The centre of the ingot, which appears to be more impure than Zone 2, and the upper portion of which contains blowholes, both with and without segregate. There is no major pipe cavity, but there are shrinkage cavities in the centre of the ingot, and traces of the V-segregate. In the lower half of the central zone a particularly unsound area, containing segregated areas of peculiar form, is seen.

The Analysis.—The pit sample analysis was :

	%
Carbon	0.064
Manganese	0.350
Silicon	0.012
Sulphur	0.039
Phosphorus	0.010

From this it will be seen that Zone 2 is approximately the same in carbon, silicon, and manganese content as the pit sample, but is lower in sulphur and phosphorus. In Zone 3 there is a concentration of carbon and sulphur. In Zone 4 the carbon, sulphur, and phosphorus are generally higher than in the pit sample, with a concentration of these elements in the top third of the ingot.

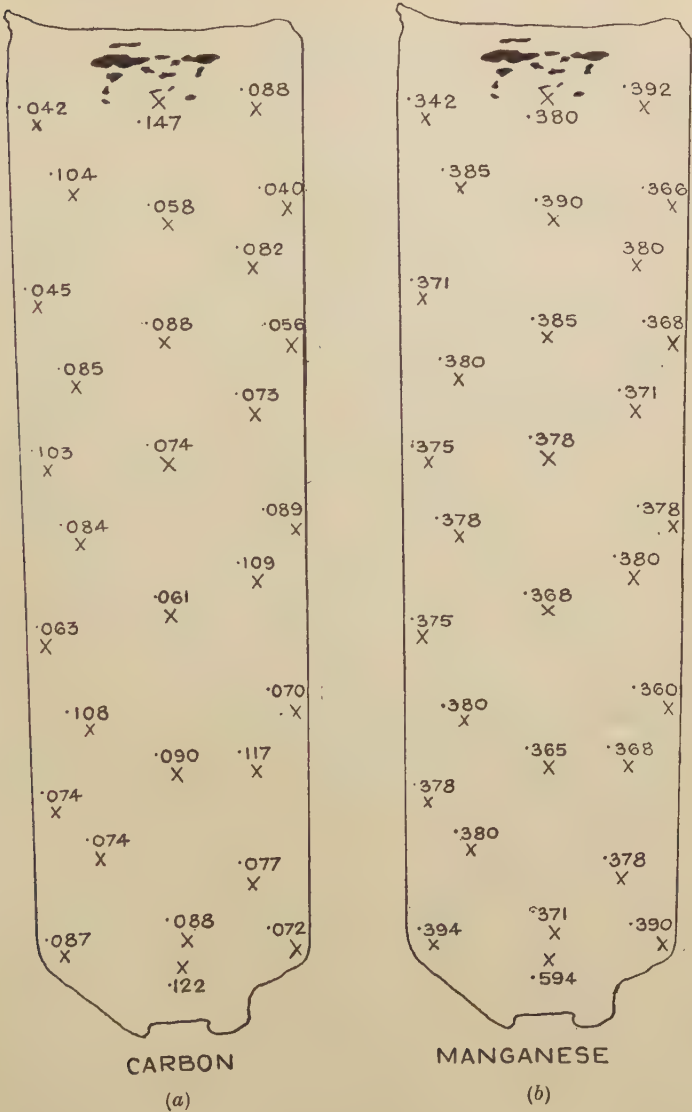
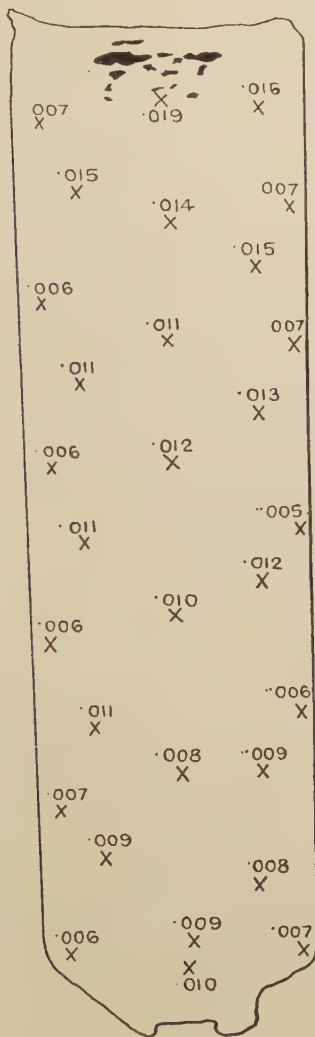


FIG. 27.—Example 24.



FIG. 27.—Example 24.



PHOSPHORUS
(e)

Fig. 27.—Example 24.

Conclusion.—From the above it would appear that after the metal has entered the mould a very thin skin first freezes, exactly as in the case of “killed” steel. Next, columnar crystals grow, and the segregates would appear to be less than in the still liquid steel in the centre; hence, in a measure, these columnar crystals appear to be of modified composition, and thus are found to be more pure than the original pit sample. During this period, the impure “mother liquor” which has been carried into the liquid steel diffuses generally, but a certain amount is later found at the top of the ingot.

The rate of freezing slows down considerably owing to the thickness of the advancing wall, the heating up of the mould, &c., and the liquid steel in the centre would appear to begin to crystallise at various points, commencing at the bottom of the ingot. The result is that the layer of carbon-, sulphur-, and phosphorus-rich mother liquid at the face of the chill crystals cannot readily diffuse, neither can the gases fully escape. They become wedged in between the two sets of crystals, and thus, apparently, Zone 3 may be accounted for.

With reference to the blowholes seen in Zone 2, and which contain little segregate, it seems highly probable that these developed after the main evolution of gas from the outer layer of crystals had carried the impure mother liquid away, and that they owe their shape mainly to the growth of the outer crystals at the time of their formation. Likewise, the globular blowholes seen in Zone 3 appear to have formed after the centre of the ingot had become “mushy,” and when the segregate was trapped between the two sets of crystals.

An explanation of the unsoundness of the bottom of this ingot has not yet been found, but it is possible that the condition of the bottom plates played some part in this.

Example 25; Plate Steel Ingot.

This ingot, of the semi-killed variety, represents a type of ingot commonly used for boiler plates and plates for general purposes. It is usual, however, to employ only the bottom half for boiler plates. The temperature of the steel when passing

down the launder was 1615° C. The data given are analyses, Figs. 28, *a* to *e*, and sulphur print and nitric etching print, Figs. 28, *f* and *g* (Plates XXIX. and XXX.). Details of the mould (*J*) are given in Fig. 10.

Examination of Sulphur Print and Nitric Etching Print.—The following features are observable :

Zone 1 : A thin solid outer skin about $\frac{1}{2}$ in. thick.

Zone 2 : A columnar crystal zone varying from 2 in. to 3 in. in thickness, in which numerous gas cavities are seen ; these are elongated, and in some cases appear to contain segregates.

Zone 3 : A zone of conical shape containing the Λ -segregate, as seen in killed steel. At many points this segregate is pierced by blowholes.

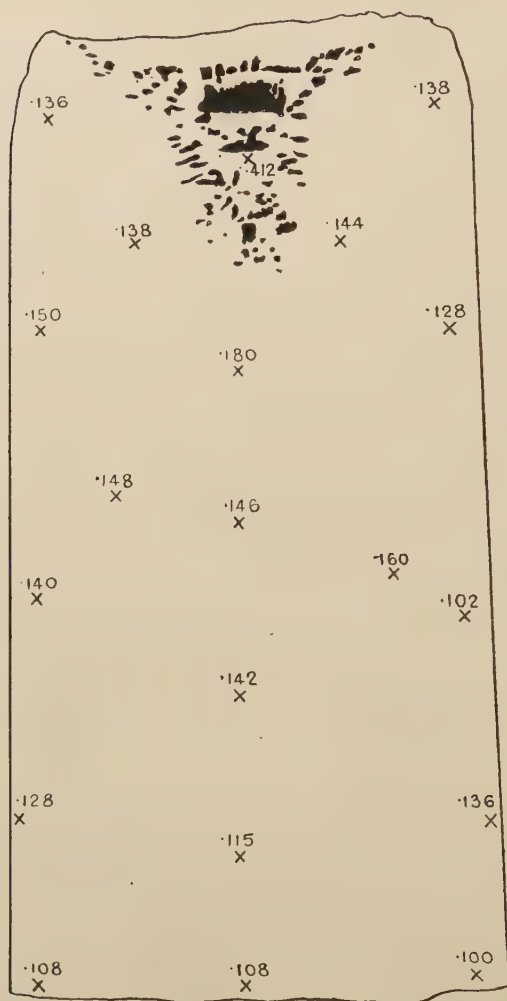
Zone 4 : The centre of the ingot, the lower half of which contains the V-segregate and shrinkage cavities, whilst the upper half contains shrinkage cavities, blowholes, and massive segregated areas.

The Analysis.—The pit sample analysis was :

	%
Carbon	0.10
Manganese	0.490
Silicon	0.012
Sulphur	0.037
Phosphorus	0.036

The analyses of the Zones 1 and 2 of the ingot were rendered difficult by the presence of blowholes containing segregate so near the surface, but it is obvious that the composition of Zone 1 is practically that of the pit sample, so far as carbon, silicon, and manganese are concerned, whilst the sulphur and phosphorus are lower. Zone 2 is a little higher in carbon than the pit sample, but very little higher in sulphur and phosphorus, except where actual segregated blowholes have been drilled.

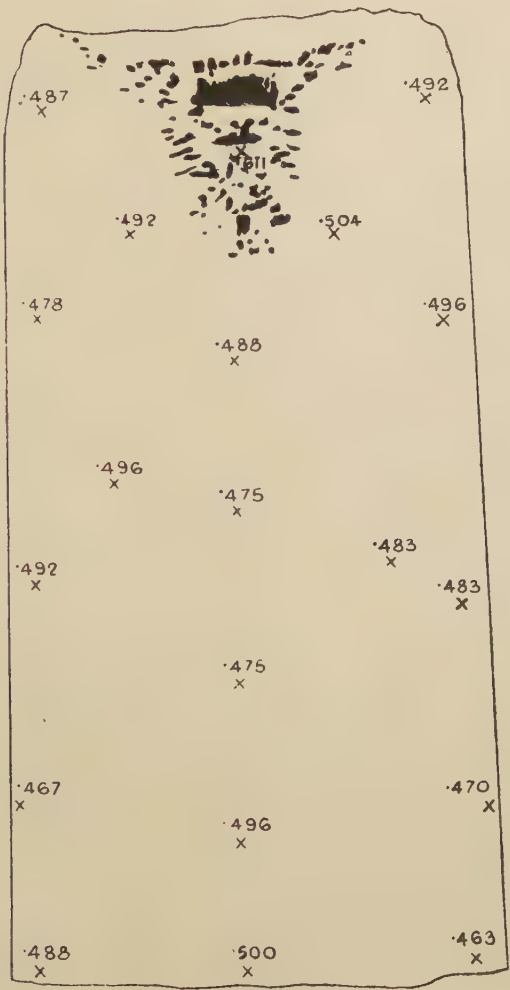
Zone 3 is high in carbon, sulphur, and phosphorus, whilst the centre of the ingot has increasing amounts of carbon, sulphur, and phosphorus from the bottom upwards. The high silicon content at the bottom of this ingot is perhaps due rather to the presence of refractory material in the mould than to any freezing effect. The



CARBON

(a)

FIG. 28.—Example 25.



MANGANESE

(b) ,

FIG. 28.—Example 25.

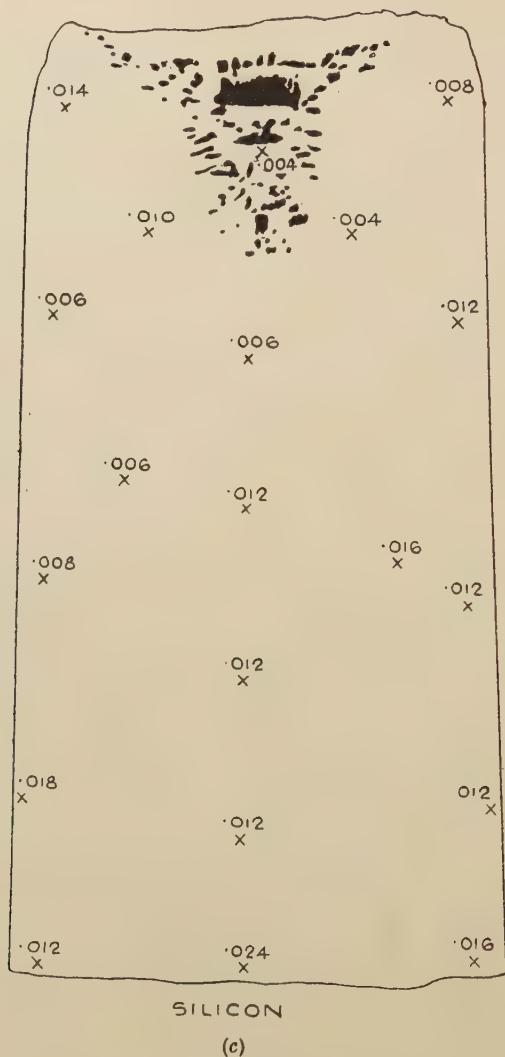
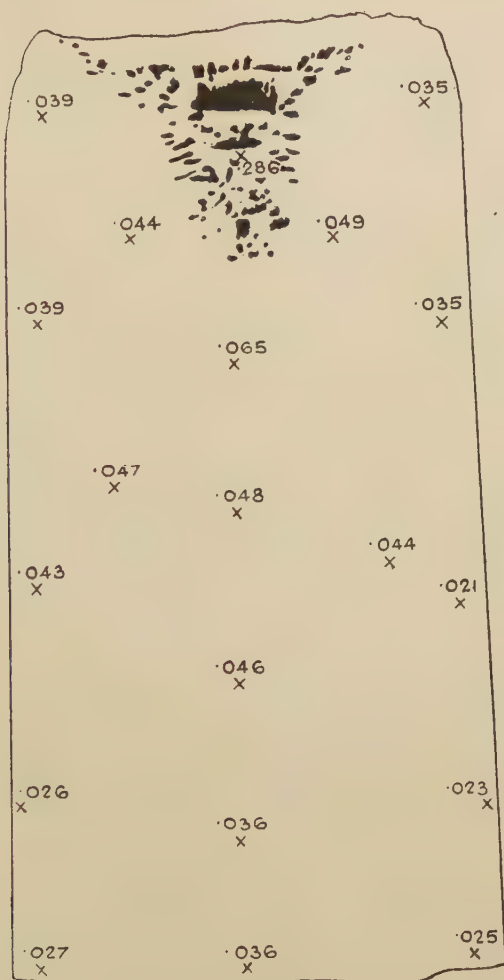


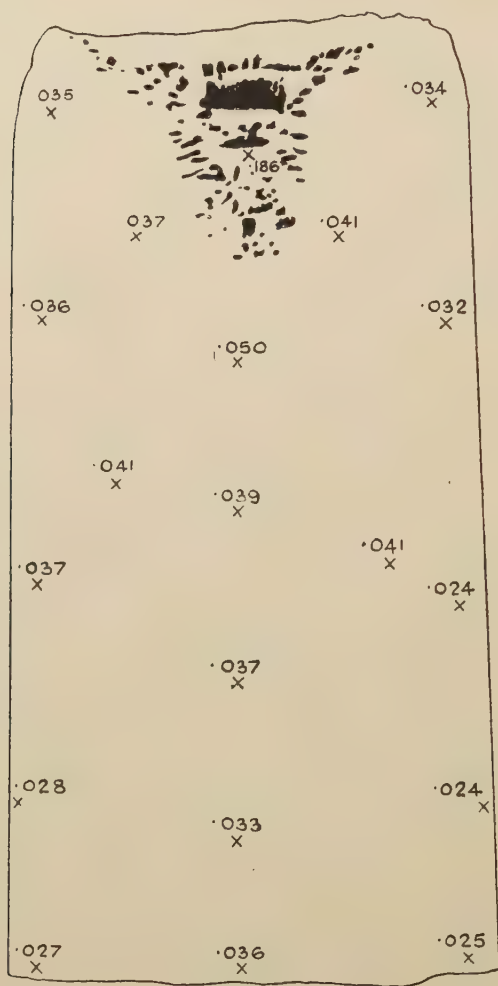
FIG. 28.—Example 25.



SULPHUR

(d) (5)

FIG. 28.—Example 25.



PHOSPHORUS

(e)

FIG. 28.—Example 25.

composition of the pool of segregate found at the top of this ingot is interesting :

						%
Carbon . . . . .	.	.	.	.	.	0.412
Manganese . . . . .	.	.	.	.	.	0.611
Silicon . . . . .	.	.	.	.	.	0.004
Sulphur . . . . .	.	.	.	.	.	0.286
Phosphorus . . . . .	.	.	.	.	.	0.186

Conclusion.—This ingot appears to be intermediate, in many respects, between the rimming steel ingot, Example 24, and a killed steel ingot ; there is a well-defined Λ -segregate and very marked segregation at the top of the ingot.

Casting records show that this steel was on the cold side, and this no doubt accounts for the presence of blowholes containing segregate so near the skin of the ingot, and for the large number found with the Λ -segregate.

The absence of any large number of blowholes at the bottom of the ingot indicates that the rate of cooling was comparatively slow, and that much of the gas escaped before any serious interference due to the freezing of the steel occurred.

Example 26 ; Plate Steel Ingot.

This ingot is of the same type as Example 25, but it was cast 30° C. hotter, the steel running down the launder at a temperature of 1645° C. (corrected), and at a somewhat slower rate. The data given are analyses, Figs. 29, *a* to *e*, and sulphur print and nitric etching print, Figs. 29, *f* and *g* (Plates XXXI. and XXXII.). Details of the mould (*K*) are given in Fig. 11.

Examination of Sulphur and Nitric Etching Prints.—In this ingot six zones are recognisable :

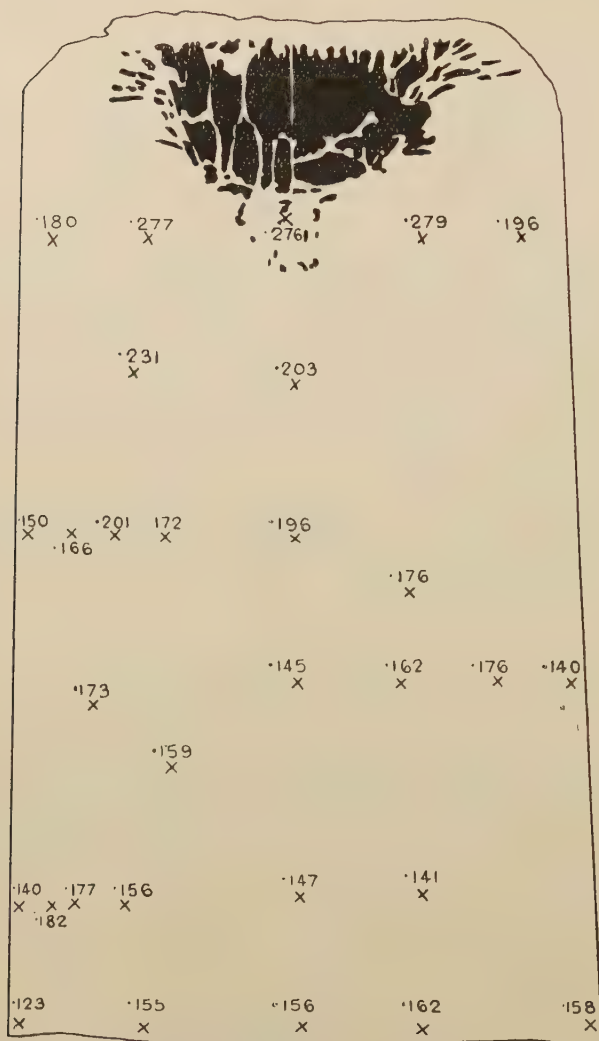
Zone 1 : A thin solid outer skin $\frac{1}{2}$ in. deep.

Zone 2 : A chill crystal zone 2 in. thick, containing elongated blowholes, but which are free from segregate.

Zone 3 : A layer of blowholes containing segregate.

Zone 4 : A conical area between Zone 3 and Zone 5 free from segregate or blowholes.

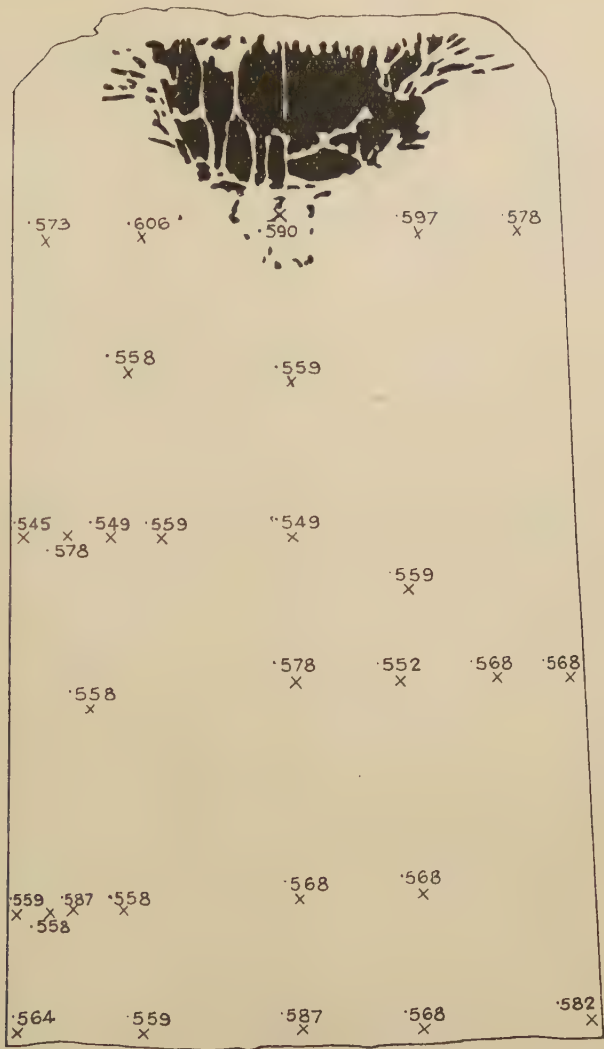
Zone 5 : The Λ -segregate.



CARBON

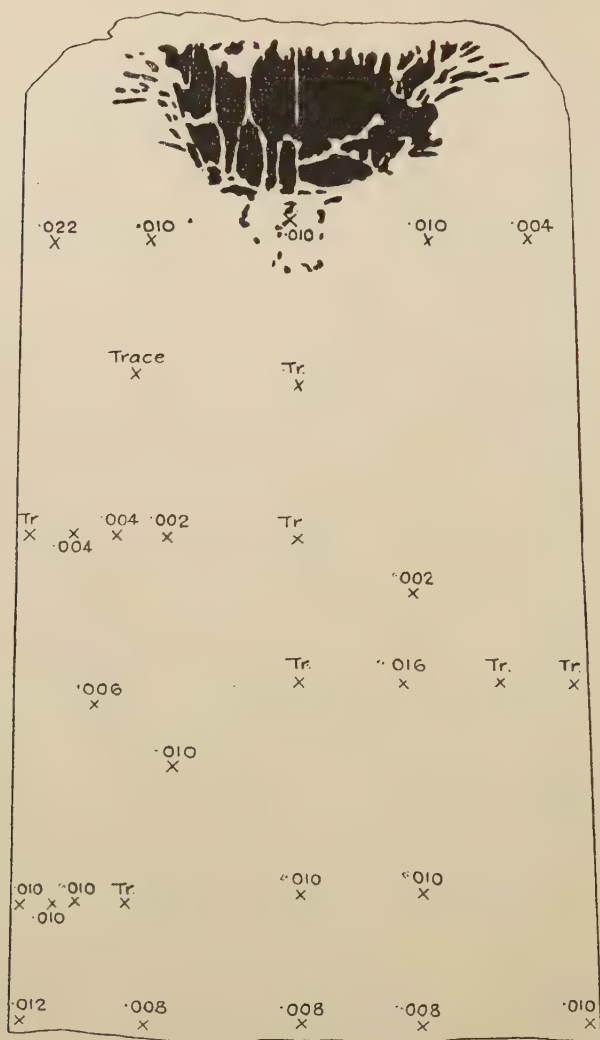
(a)

FIG. 29.—Example 26.



MANGANESE
(b)

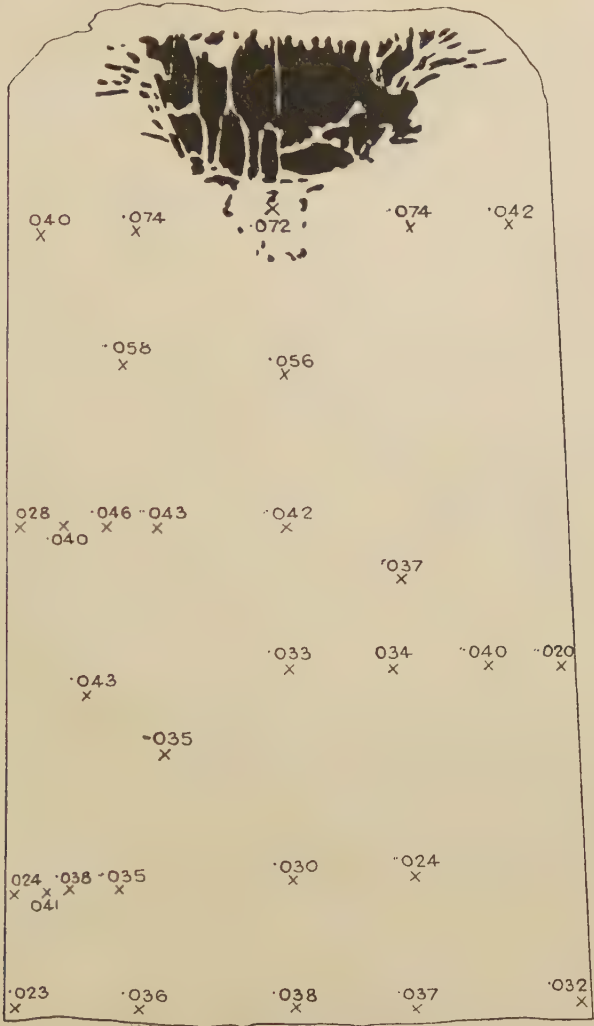
FIG. 29.—Example 26.



SILICON

(c)

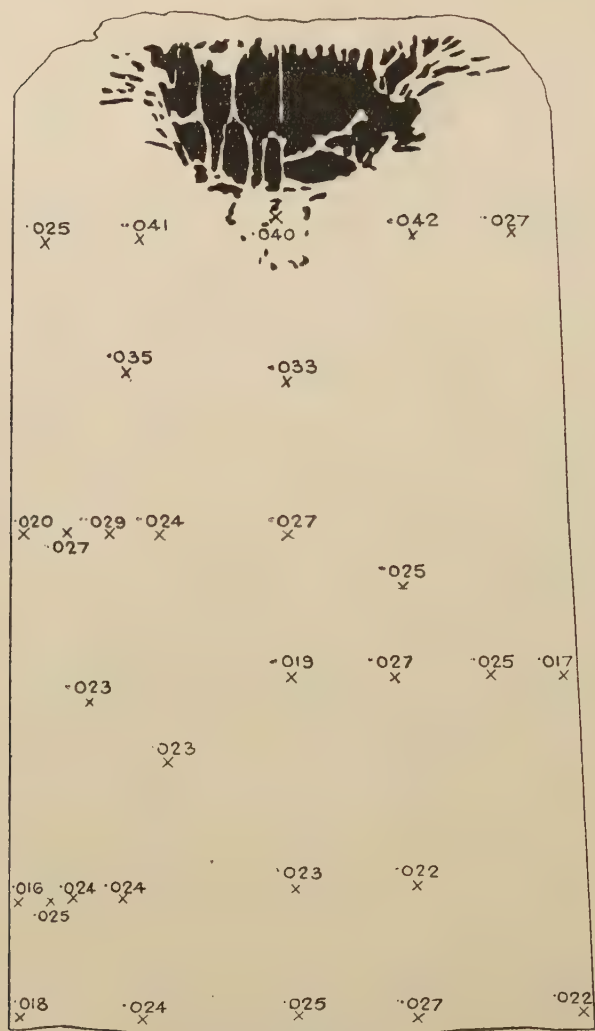
FIG. 29.—Example 26.



SULPHUR

(d)

FIG. 29.—Example 26.



PHOSPHORUS

(e)

FIG. 29.—Example 26.

Zone 6: The centre of the ingot. This was sound at the bottom, but contained isolated segregates higher up, and cavities and segregate towards the top end.

The Analysis.—The pit sample analysis was :

	%
Carbon	0·14
Manganese	0·52
Silicon	0·024
Sulphur	0·039
Phosphorus	0·024

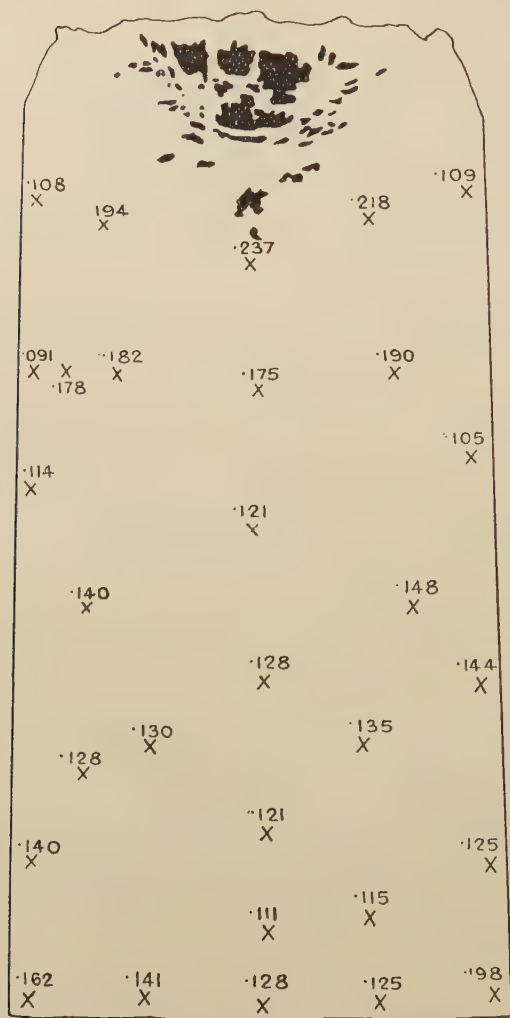
The analysis reveals characteristics in this ingot similar to those in the previous one, with the exception that the silicon is exceptionally low throughout the whole ingot.

Zones 1 and 2 have practically the same carbon and manganese contents as the pit sample, but the sulphur and phosphorus are lower. Zone 4 is somewhat high in carbon, but normal in sulphur and phosphorus, whilst Zone 5, the Λ -segregate, is high in carbon, sulphur, and phosphorus, and increasingly so towards the top end of the ingot. Zone 6, the centre of the ingot, has practically the same composition as the pit sample at the bottom end, but increases in carbon, sulphur, and phosphorus towards the top end.

Conclusion.—The data from this ingot indicate that the higher casting temperature and the slower rate of teeming have allowed the gas to get away more readily, and, further, have resulted in the minimisation of segregation. It is apparent that the position of the Λ -segregate is closely connected with teeming conditions—temperature, rate of pouring, and degree of wildness. The very low silicon result is difficult to explain, and is by no means an uncommon occurrence in steel of this class.

Example 27 ; Plate Steel Ingot.

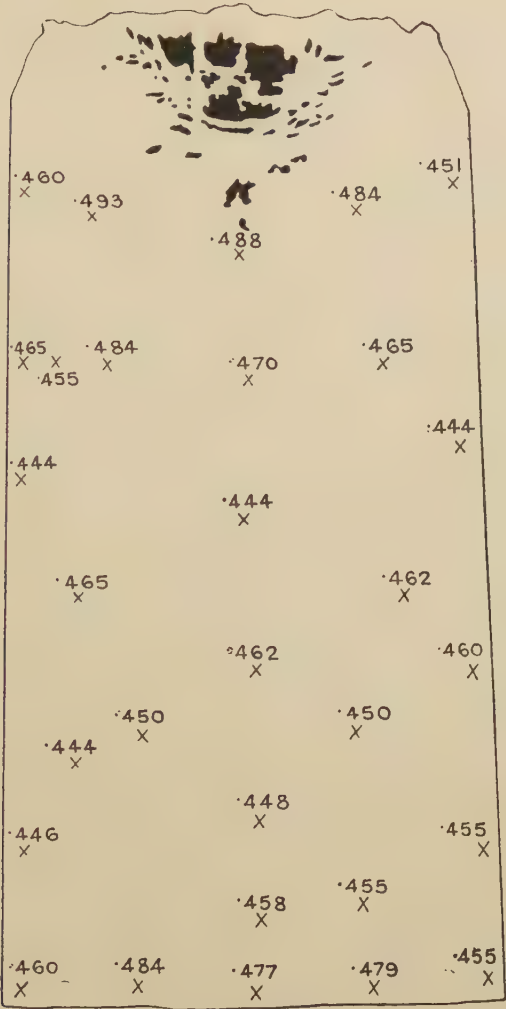
This is of the same type as Example 26, cast rather on the cold side (the temperature at the launder was 1625° C., corrected), and slowly, but the steel was much “wilder.” The data given are analyses and mould details, Figs. 30, *a* to *e*, and sulphur print and nitric etching print, Figs. 30, *f* and *g* (Plates XXXIII. and XXXIV.). Details of the mould (*J*) are given in Fig. 10.



CARBON

(a)

FIG. 30.—Example 27.



MANGANESE

(b)

FIG. 30.—Example 27.

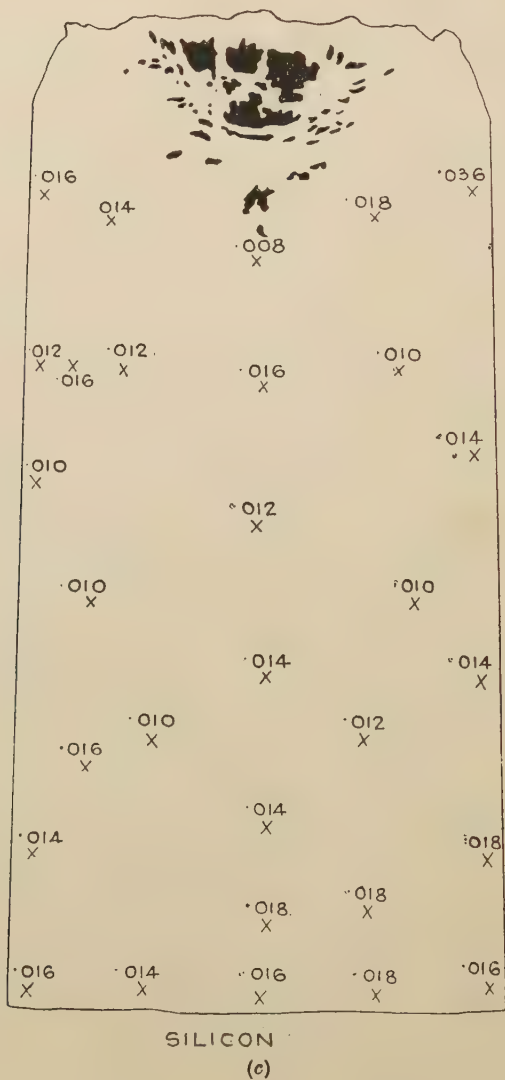
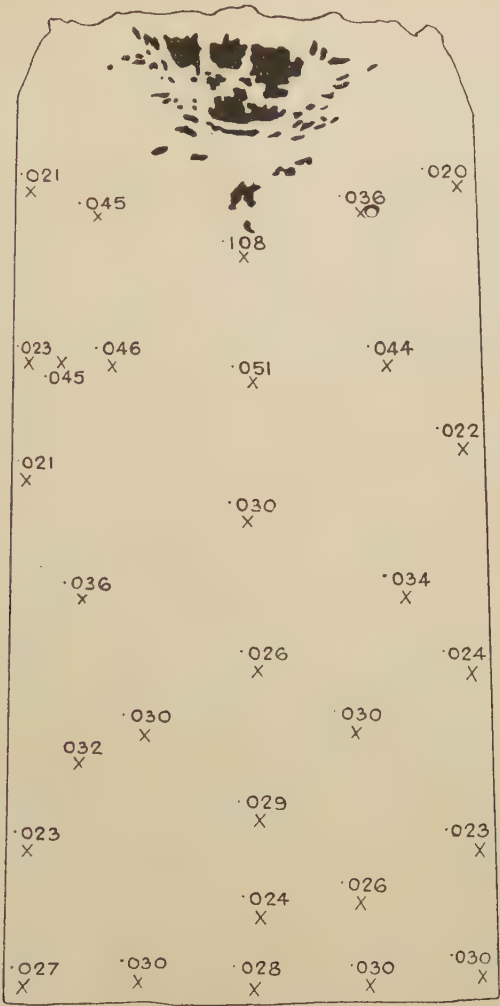
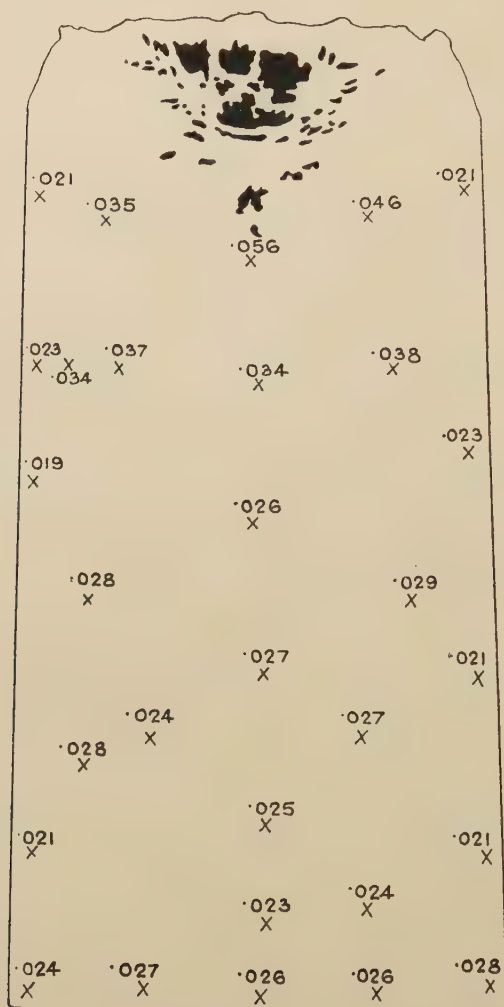


FIG. 30.—Example 27.



SULPHUR
(d)

FIG. 30.—Example 27.



PHOSPHORUS

(e)

FIG. 30.—Example 27.

Examination of the Sulphur Print and Nitric Etching Print.

—Four zones are to be seen :

Zone 1 : A very thin outer shell.

Zone 2 : A shell varying from 2 in. to 4 in. in thickness.

The first $1\frac{1}{2}$ in. of this is solid, but the remainder contains numerous large gas cavities. A few of these contain segregates, but most of them are free from such matter.

Zone 3 : A conical zone containing segregates of the Λ -type, but relatively few blowholes.

Zone 4 : The centre of the ingot—sound and free from segregation at the bottom, but having the well-defined V-segregate on the centre line, also cavities of the shrinkage type.

The Analysis.—The pit sample analysis was :

					%
Carbon	.	.	.	.	0·130
Manganese	.	.	.	.	0·480
Silicon	.	.	.	.	0·020
Sulphur	.	.	.	.	0·039
Phosphorus	.	.	.	.	0·024

The distribution of the various elements in this ingot is very similar to that in the previous ingot, with the exception that Zone 2 is somewhat high in carbon at the bottom end of the ingot and low towards the top ; also, the centre line of the ingot is surprisingly free from segregation, except, of course, at the top end. The silicon, it will be noticed, is also low throughout the ingot, as compared with the pit sample.

Conclusion.—The data obtained from this ingot yield similar conclusions to those previously arrived at with respect to Examples 25 and 26.

Had the casting temperature been higher, it seems probable that much of the gas forming the blowholes in Zone 2 would have escaped to the top of the ingot, and in so doing would have removed with them much of the segregate found in Zone 3.

Example 28 ; Plate Steel Ingot.

This ingot weighed 8 tons, and was made by the acid open-hearth process. It was top-cast into a parallel split mould,

M, Fig. 13, the temperature of the furnace (back wall) being 1590°C . and of the steel in the launder 1615°C . The rate of teeming was $3\frac{1}{2}$ tons per minute. The charge contained 70 per cent. of steel scrap. One ton of ore (Fe_2O_3 , 89 per cent.) was used to work the charge, and no limestone. The ferro-manganese was added to the ladle.

The Analysis.—The pit sample analysis was :

	%
Carbon	0.155
Manganese	0.49
Sulphur	0.059
Phosphorus	0.061

The analysis of the tapping slag was :

	%		%
SiO_2	52.5	MgO	0.34
FeO	27.4	Al_2O_3	4.9
MnO	13.2	TiO_2	0.25
CaO	0.75		

The data given include analyses of drillings taken at different points on the half-section, Figs. 31, *a* to *d*, and sulphur prints, Figs. 31, *e* to *g* (Plates XXXV. and XXXVI.). The sulphur print shows a thin outer shell of steel, increasing in thickness towards the top, of greater purity than the average composition. Its presence is also indicated by the analyses of the skin drillings. This zone is more clearly seen in Fig. 31*f*, which shows a half-size section of the sulphur print taken at one edge about 1 ft. from the top. It is noteworthy that the widening of the zone in the upper part coincides with a gradual increase in number and size of subcutaneous blowholes. There can be no doubt that the beginnings are here seen of a type of heterogeneity, illustrated by Example 24, common to all unkilld or partly killed low-carbon steels. The Λ -segregates are quite as pronounced as in piping steels, and are intersected here and there by blowholes into which rising segregate appears to have flowed. Fig. 31*g* shows an example of one of these at about half-size. Cavities are also to be seen in the head of the ingot apparently containing rich segregate, which appears to have welled up into them. This effect may have been caused by the liberation of gases in parts nearer the centre where the last portions to freeze would be situated.

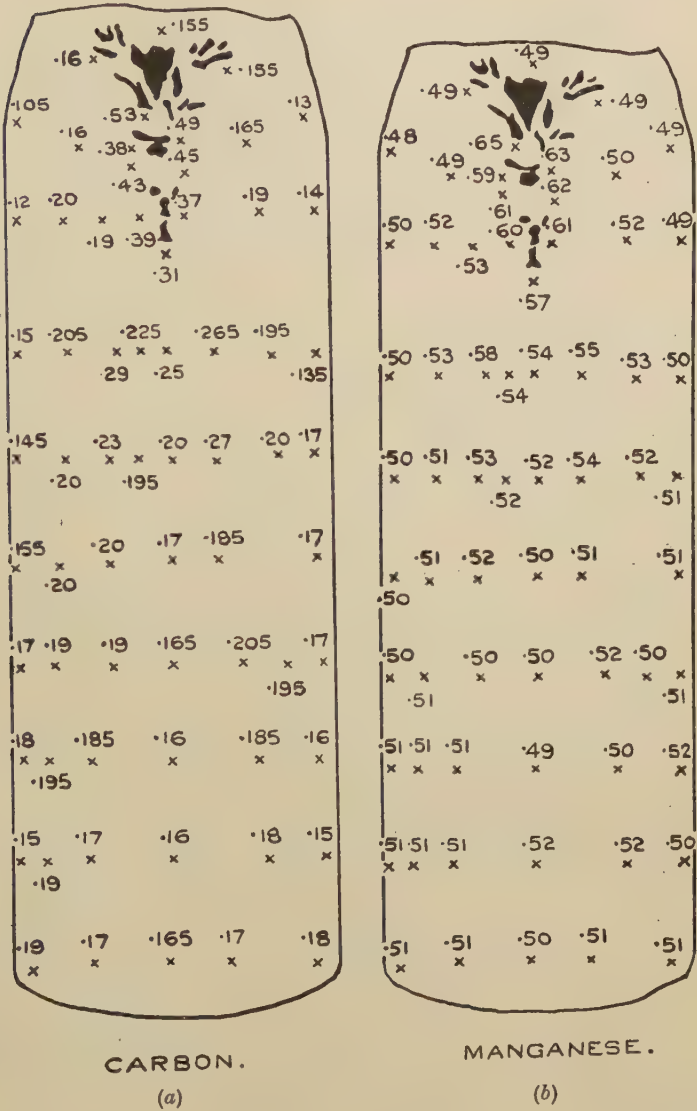


FIG. 31.—Example 28.

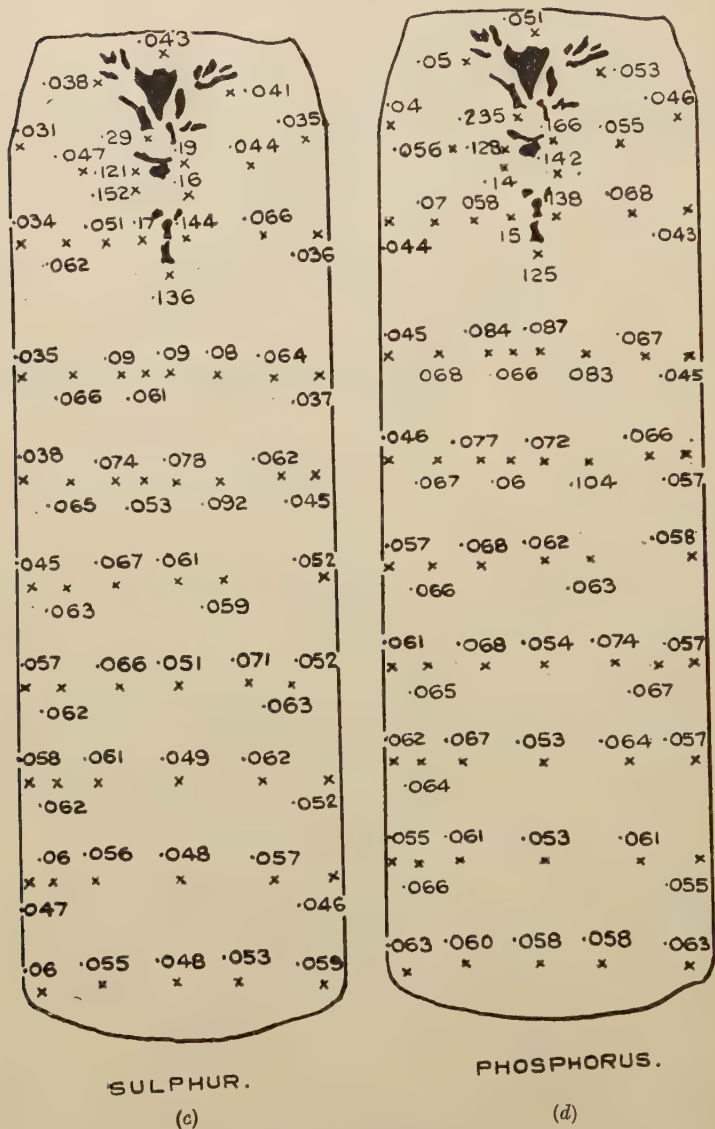


FIG. 31.—Example 28.

In order to obtain some idea of the distribution of silicates in the ingot, a number of silicon estimations were made as follows: 20 grm. of drillings, in each case, were dissolved in hydrochloric acid, and the insoluble residue, after evaporation and re-solution, collected by filtration on an ashless pulp filter. After thorough washing, the pulps were ignited and the silica content of the residues found by treatment with hydrofluoric acid and a drop of sulphuric acid in a weighed platinum crucible. The final residues were found to consist of oxides of iron and manganese. The results obtained are given below:

Position.	Weight of Residue. Grm.	Loss in HF. Grm.	Silicon. %
Second row from bottom, middle hole . . .	0.0115	0.007	0.016
„ „ „ holes 3 and 5 mixed . . .	0.008	0.005	0.012
Seventh row from bottom, middle hole . . .	0.005	0.025	0.006
„ „ „ holes 4 and 6 mixed . . .	0.006	0.003	0.007

These figures make it clear that the silicate inclusions are in greater amount in the lower part of the ingot, a result which fully accords with the recent work of Dickenson on the subject.

Example 29 ; Basic Free-Cutting Steel Ingot.

This is an ingot weighing 3 tons 6 cwt., teemed from a 50-ton basic open-hearth cast having specially high sulphur and phosphorus contents. The analyses of the tapping slag and metal were as follows:

Metal.			%	Slag.			%
Carbon	.	.	0.04	SiO ₂	.	.	8.0
Manganese	.	.	0.20	P ₂ O ₅	.	.	11.5
Silicon	.	.	...	CaO	.	.	39.1
Sulphur	.	.	0.034	Fe	.	.	15.8
Phosphorus	.	.	0.046				

Additions made to the furnace consisted of 12 cwt. of pig iron and 4 cwt. of spiegel; $7\frac{1}{4}$ cwt. of 75 per cent. ferro-manganese, 2 cwt. of silicon-manganese (20/70), and 150 lb. of sulphur and 450 lb. of ferro-phosphorus were added to the ladle.

The Analysis.—The pit sample analysis was as follows :

Carbon	.	.	.	.	.	%
Manganese	.	.	.	.	.	0.12
Silicon	.	.	.	.	.	0.66
Sulphur	.	.	.	.	.	0.03
Phosphorus	.	.	.	.	.	0.113
						0.098

As regards the temperature at the finishing of the charge, the following data are available : Furnace 1620° C. ; launder stream 1635° C., and casting stream 1575° to 1570° C. (corrected).

The speed of casting was at the rate of 41 cwt. per minute, and the mould employed is shown in Fig. 9.

This ingot is of interest because, although the silicon content is very low—0.03 per cent.—and no additions of aluminium are made, yet the ingot shows the typical structure and features of ingots of “killed” steel.

The evolution of gases, typical of low-silicon or “unkilled” steel, is prevented by the high content of sulphur. This sulphur acts as a powerful deoxidising agent. In Figs. 32, *a* to *d*, will be found the results of analyses, and a sulphur print appears in Fig. 32*e* (Plate XXXV.).

It will be noted that the ingot displays no blowholes, the major segregation is confined to the feeder-head, and the minor segregation in the body of the ingot is of the same order as in the “solid” ingots of the First Report. For so high a sulphur and phosphorus content, the steel shows a marked degree of uniformity of composition. The pool of segregate below the head cavity is of interest, having the following composition :

Carbon	.	.	.	.	.	%
Manganese	.	.	.	.	.	0.31
Sulphur	.	.	.	.	.	0.71
Phosphorus	.	.	.	.	.	0.249
						0.239

Example 30 ; Plate Steel Ingot.

This plate steel ingot, weighing 7 tons 14 cwt., was cast in mould *L* from acid open-hearth steel. The analysis of the cast was as follows :

Carbon	.	.	.	.	.	%
Manganese	.	.	.	.	.	0.19
Silicon	.	.	.	.	.	0.51
Sulphur	.	.	.	.	.	0.075
Phosphorus	.	.	.	.	.	0.040
						0.042

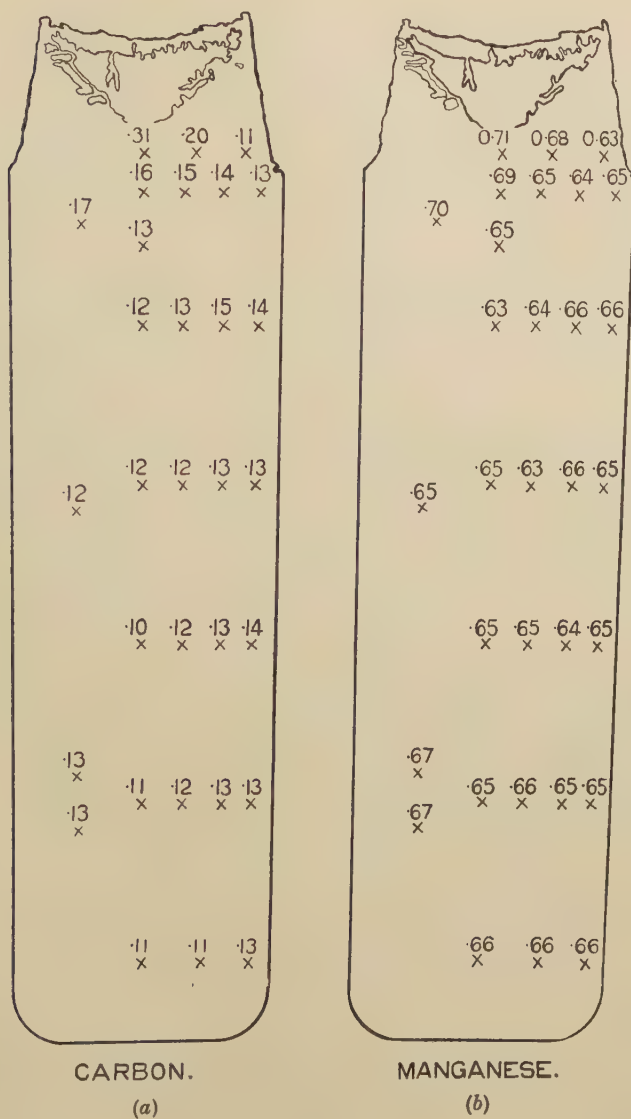


FIG. 32.—Example 29.

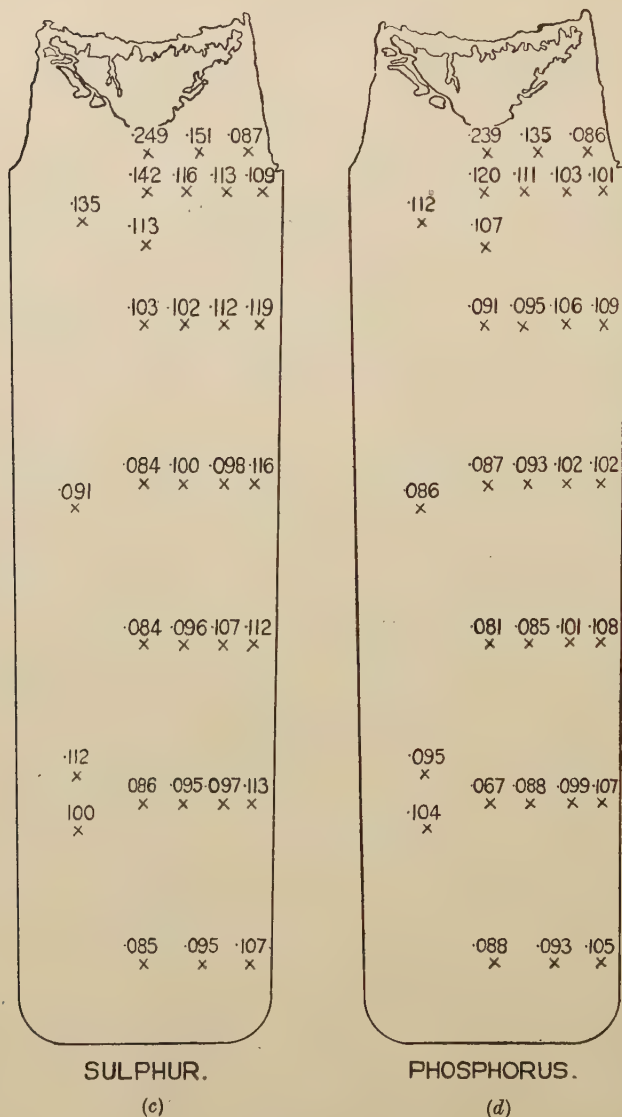


FIG. 32.—Example 29.

The analyses of the slags during the conduct of the charge were as follows :

Time.	SiO ₂ . %	FeO. %	MnO. %	CaO. %
Melted . . .	39·8	42·19	12·83	2·1
After lime . . .	50·5	24·05	18·23	3·8
Boiling . . .	50·0	21·82	19·16	5·7
11 A.M. . . .	36·6	41·83	14·88	3·4
11.30 A.M. . .	51·7	27·86	13·02	3·2
12.0 noon . . .	59·3	21·60	12·09	3·7
12.30 P.M. . .	49·4	23·44	14·60	4·3
Final (tapping) . .	51·8	27·43	14·14	3·3

The analyses are charted in Figs. 33, *a* to *e*, and a sulphur print and nitric etching print will be found in Figs. 33, *f* and *g* (Plate XXXVII.).

The ingot formed part of a 55½-ton cast. The tapping temperature was 1660° C.; ferro-manganese and silicon-manganese were added to the ladle, and a 1-in. nozzle was used.

The sulphur print shows that this steel is intermediate between the open steel ingots shown in Examples 25, 26, and 27, and the piping steel described in the First Report.

The characteristic features of this ingot are :

Zone 1.—An outside skin of solid metal.

Zone 2.—A series of blowholes underneath the skin. They vary in length, but increase in amount and dimensions towards the top end. These small blowholes grow out from the ingot wall almost, but not exactly, at right angles, having a slight upward direction similar to the growth of chill crystals in piping steel.

Zone 3.—The remaining surface of the ingot resembles closely that of piping steel, as described in the First Report, namely :

- (a) A pipe at the top end.
- (b) V-segregates extending from the bottom of the pipe down the centre of the ingot.
- (c) Cone segregates, having the base at the bottom end.

This ingot is typical of the class of steel used for boiler plates, the bottom end being used for that purpose; a portion of the top is used for ship plates.

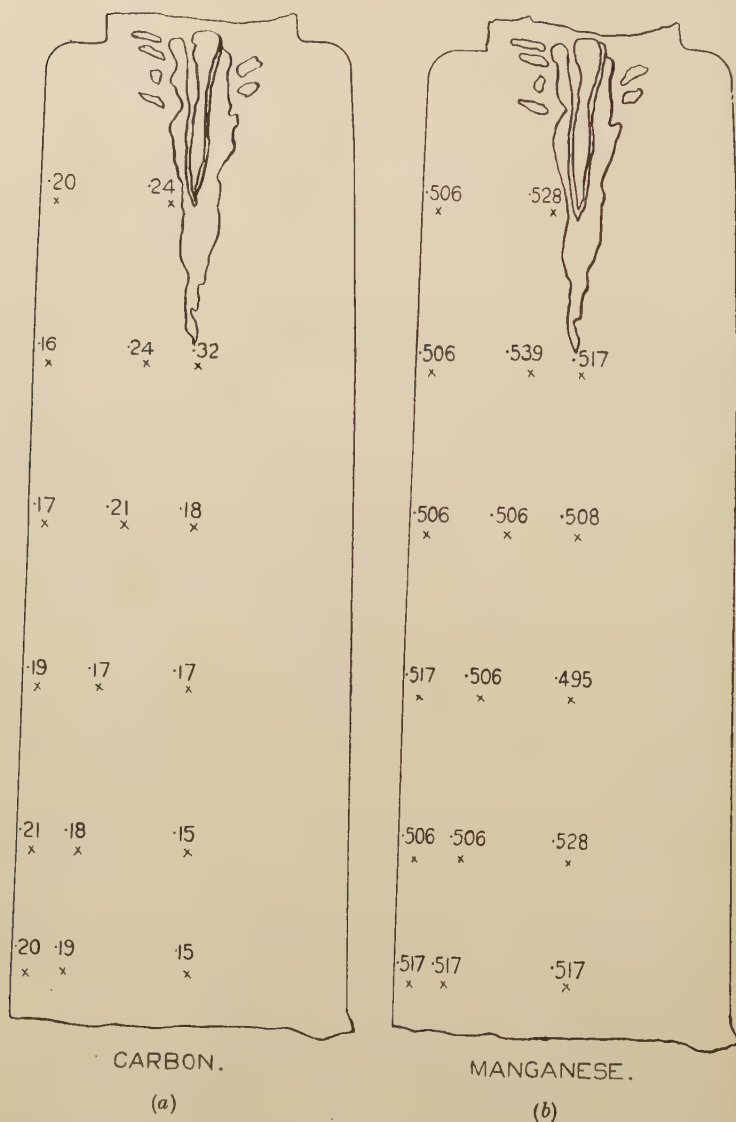


FIG. 33.—Example 30.

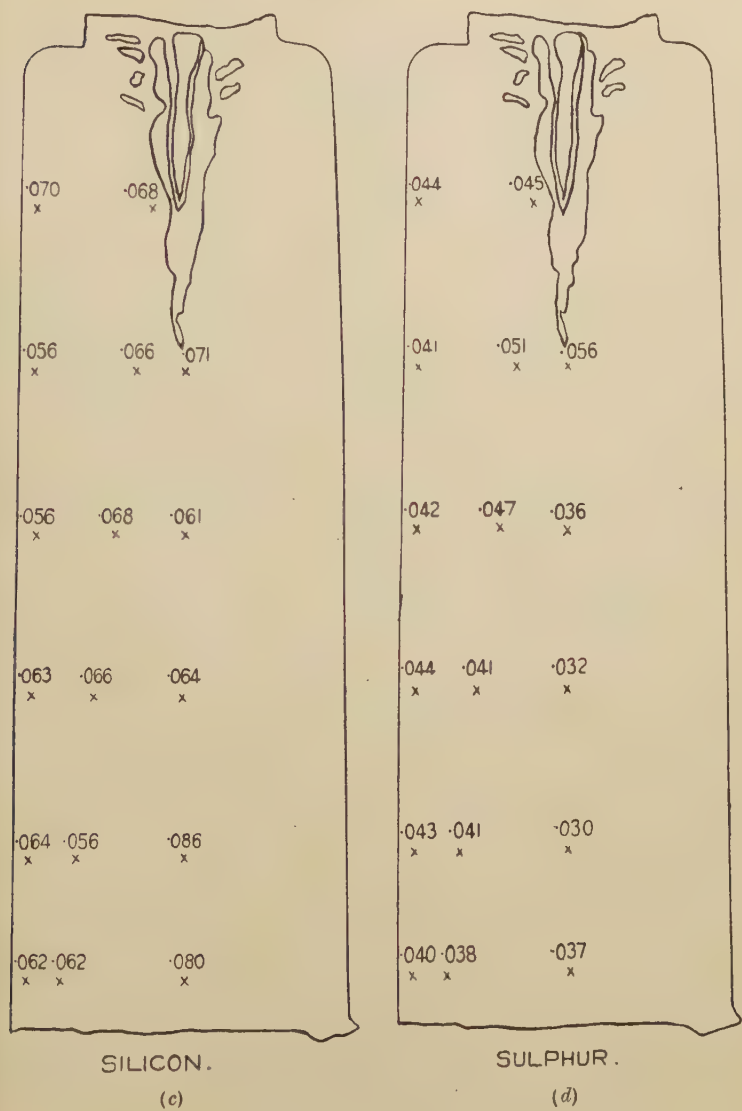
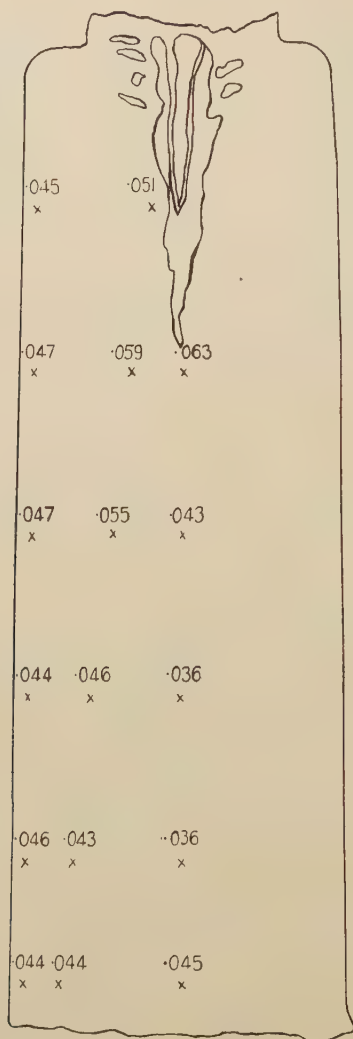


FIG. 33.—Example 30.



PHOSPHORUS.

(e)

FIG. 33.—Example 30.

Example 31 ; Plate Steel Ingot.

This ingot weighed 7 tons 14 cwt., and was cast in mould *L*, Fig. 12. The analysis of the cast was :

	%
Carbon	0·13
Manganese	0·50
Sulphur	0·033
Phosphorus	0·014

A little aluminium may have been added during teeming. Charts of the analyses of the ingot will be found in Figs. 34, *a* to *e*, and Figs. 34, *f* and *g* (Plates XXXVIII. and XXXIX.), are a sulphur print and nitric etching print respectively.

The sulphur print shows that this steel is of the same class as Example 30. The characteristic features are :

Zone 1.—An outside skin of solid metal.

Zone 2.—A series of blowholes underneath the skin, which, like those in Example 30, increase in amount and length as they approach the top of the ingot. They also extend in a direction similar to chill crystals in piping steel.

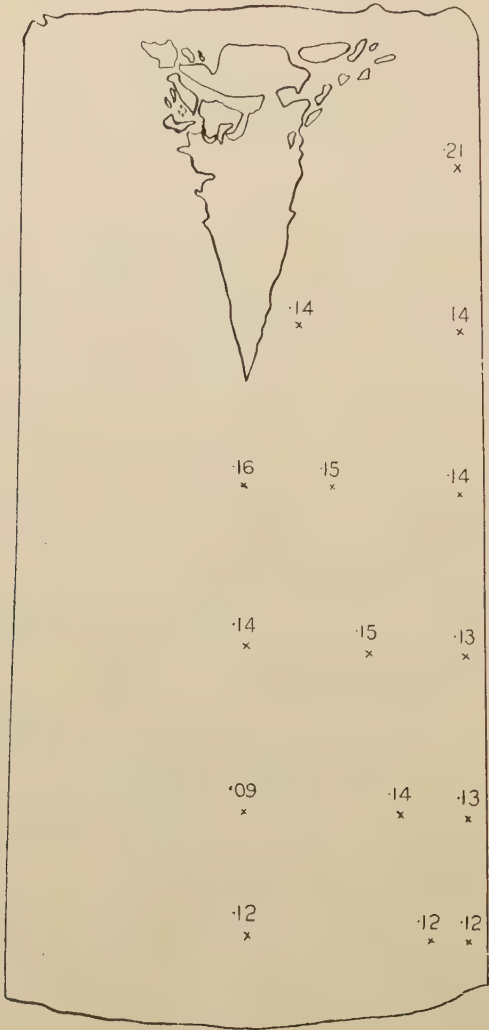
Zone 3.—The remaining section of the ingot is similar to that observed in piping steel.

- (a) A central pipe. In this case the surface of the pipe contains a dark etching material, but no reason can be assigned for its presence.
- (b) A very slight trace of central segregation extending from the bottom of the pipe. The usual *V*-segregates are not pronounced.
- (c) A trace of the cone segregate only noticeable near the centre, but disappearing before the central pipe and the bottom end are reached.

The surfaces of Examples 30 and 31 when etched by copper ammonium chloride reagent show up the blowholes and their extent and position better than the sulphur prints.

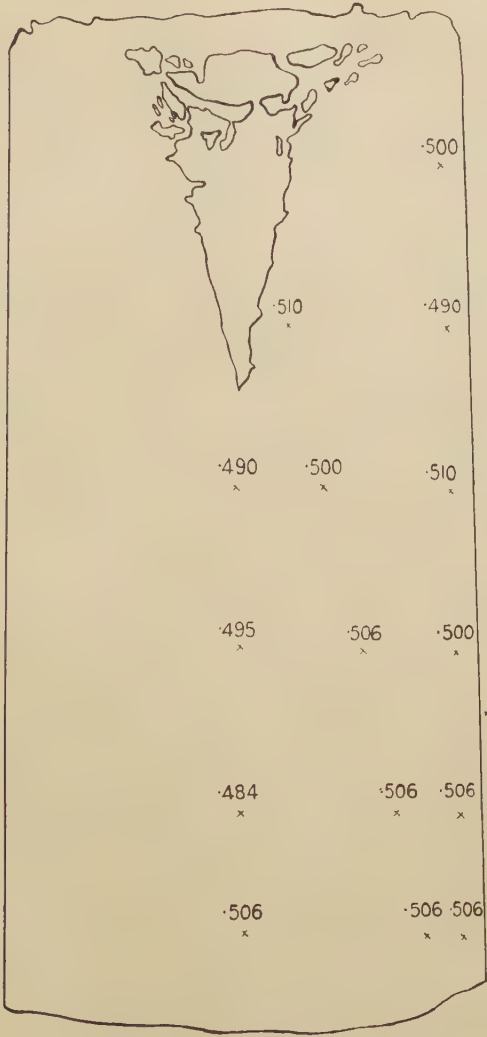
Example 32 ; Acid Siemens Steel Ingot.

This ingot, cast many years ago, is included as representing early practice. It was cast from the bottom in an octagonal



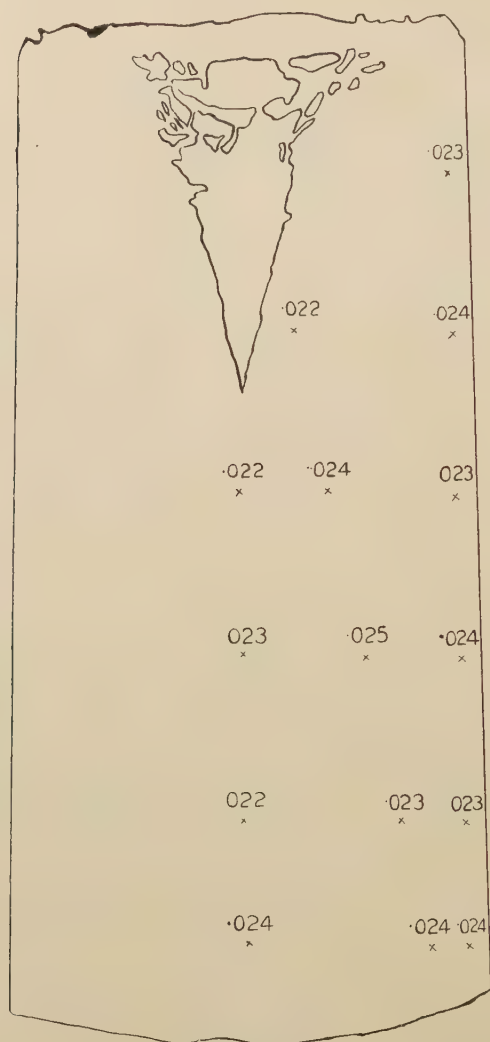
CARBON.
(a)

FIG. 34.—Example 31.



MANGANESE.
(b)

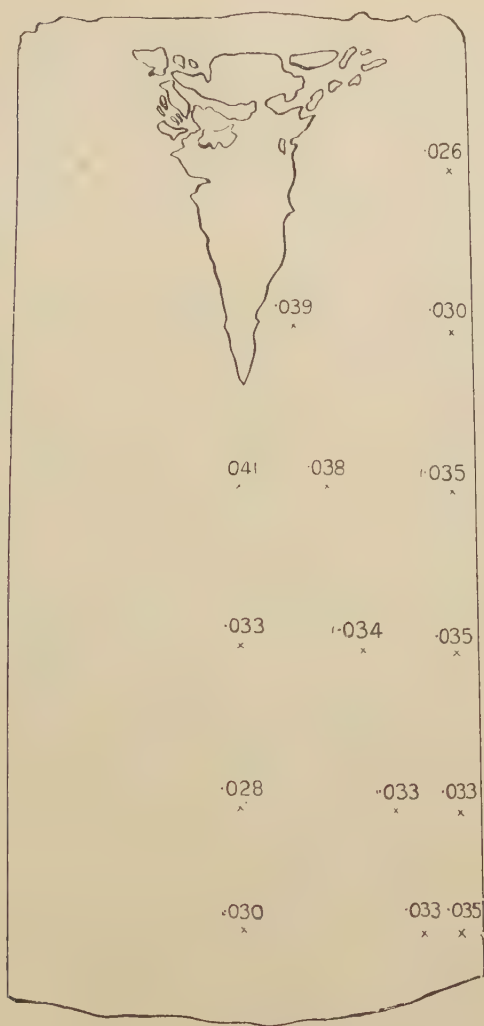
FIG. 34.—Example 31.



SILICON.

(c)

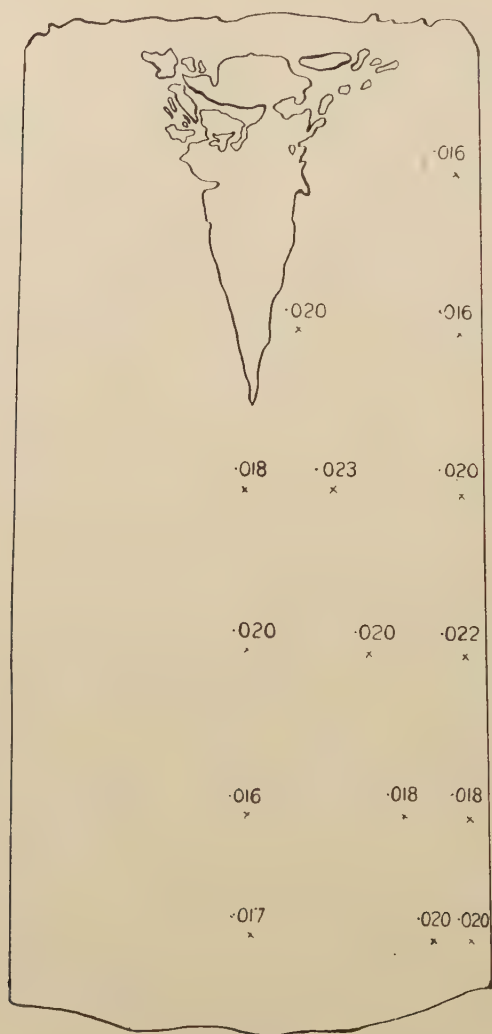
FIG. 34.—Example 31.



SULPHUR.

(d)

FIG. 34.—Example 31.



PHOSPHORUS.

(e)

FIG. 34.—Example 31.

chill mould tapering from $14\frac{3}{4}$ in. across the flats at the bottom to $10\frac{1}{2}$ in. across the flats at the top. The mould was close-topped, and for the greater part of its length was 3 in. thick (see mould *B*, Fig. 2). The total weight of the finished ingot was 23 cwt., so that for a comparison of its degree of segregation it is similar to Example 2, described in the First Report.

Analyses of the ingot are shown in Figs. 35, *a* to *e*, and a polished section and nitric etching print in Figs. 35, *f* and *g* (Plate XL.).

Description of the Ingot.—The major portion of the cavity was contained in a space within a foot of the top of the ingot, but numerous small cavities were found below this, and were even present along the axis of the ingot to within a height of 12 in. from the bottom. The print shows the greater part of the segregation to exist at the centre line of the ingot in the top 15 in., just below the major portion of the cavity. This disposition of the segregation is confirmed by the analysis, which shows very little variation, except where indicated by the darkly coloured portion of the sulphur print mentioned above.

Comparison of Example 32 with Example 2 (First Report).—For the purpose of this comparison, the seven standard positions were taken,¹ and the analyses of the two ingots at the various positions have been tabulated in Table XVIII.

From a comparison of these figures and of the prints, it will be seen that the two ingots behave very much alike as far as the layout of the segregates is concerned. The main points of difference are as follows :

- (1) The lower central zone of relatively pure material is not so marked in Example 32.
- (2) The region of maximum segregate is drawn out over a long length of the axis of the ingot near the cavity at the top in Example 32, whereas in Example 2 the segregate has collected in a more or less hemispherical formation bordering on the cavity.
- (3) There is a tendency for the carbon content in Example 32 to increase with the height in the ingot. This tendency is not apparent in Example 2.

¹ See First Report, *Journal of the Iron and Steel Institute*, 1926, No. I. p. 91; the positions are also shown in Figs. 23, *c* and *d*, p. 456.

<div> <div>x0.60</div> <div>x0.60</div> <div>x0.64</div> <div>x0.64</div> </div> <div> <div>x0.61</div> <div>x0.61</div> <div>x0.64</div> <div>x0.65</div> </div> <div> <div>x0.61</div> <div>x0.61</div> <div>x0.63</div> <div>x0.63</div> </div> <div> <div>x0.61</div> <div>x0.61</div> <div>x0.62</div> <div>x0.64</div> </div> <div> <div>x0.60</div> <div>x0.61</div> <div>x0.62</div> <div>x0.64</div> </div> <div> <div>x0.61</div> <div>x0.61</div> <div>x0.62</div> <div>x0.62</div> </div> <div> <div>x0.60</div> <div>x0.61</div> <div>x0.64</div> <div>x0.62</div> </div> <div> <div>x0.63</div> <div>x0.62</div> <div>x0.66</div> <div>x0.72</div> </div> <div> <div>x0.61</div> <div>x0.62</div> <div>x0.64</div> <div>x0.72</div> </div> <div> <div>x0.61</div> <div>x0.60</div> <div>x0.66</div> <div>x0.62</div> </div> <div> <div>x0.63</div> <div>x0.62</div> <div>x0.66</div> <div>x0.72</div> </div> <div> <div>x0.63</div> <div>x0.61</div> <div>x0.66</div> <div>x0.74</div> </div> <div> <div>x0.62</div> <div>x0.61</div> <div>x0.63</div> <div>x0.91</div> </div> <div> <div>x0.65</div> <div>x0.60</div> <div>x0.76</div> </div>	<div> <div>x0.66</div> <div>x0.63</div> <div>x0.65</div> <div>x0.64</div> </div> <div> <div>x0.67</div> <div>x0.65</div> <div>x0.64</div> <div>x0.64</div> </div> <div> <div>x0.66</div> <div>x0.63</div> <div>x0.65</div> <div>x0.64</div> </div> <div> <div>x0.67</div> <div>x0.64</div> <div>x0.65</div> <div>x0.66</div> </div> <div> <div>x0.66</div> <div>x0.66</div> <div>x0.66</div> <div>x0.63</div> </div> <div> <div>x0.67</div> <div>x0.65</div> <div>x0.66</div> <div>x0.63</div> </div> <div> <div>x0.68</div> <div>x0.66</div> <div>x0.65</div> <div>x0.65</div> </div> <div> <div>x0.68</div> <div>x0.66</div> <div>x0.65</div> <div>x0.65</div> </div> <div> <div>x0.68</div> <div>x0.66</div> <div>x0.65</div> <div>x0.68</div> </div>	<div> <div>x0.185</div> <div>x0.205</div> <div>x0.21</div> <div>x0.19</div> </div> <div> <div>x0.185</div> <div>x0.225</div> <div>x0.215</div> <div>x0.225</div> </div> <div> <div>x0.195</div> <div>x0.225</div> <div>x0.21</div> <div>x0.225</div> </div> <div> <div>x0.19</div> <div>x0.225</div> <div>x0.21</div> <div>x0.225</div> </div> <div> <div>x0.195</div> <div>x0.225</div> <div>x0.21</div> <div>x0.225</div> </div> <div> <div>x0.185</div> <div>x0.22</div> <div>x0.22</div> <div>x0.225</div> </div> <div> <div>x0.185</div> <div>x0.21</div> <div>x0.215</div> <div>x0.21</div> </div> <div> <div>x0.195</div> <div>x0.22</div> <div>x0.22</div> <div>x0.23</div> </div> <div> <div>x0.18</div> <div>x0.19</div> <div>x0.23</div> <div>x0.23</div> </div> <div> <div>x0.185</div> <div>x0.20</div> <div>x0.225</div> <div>x0.225</div> </div> <div> <div>x0.19</div> <div>x0.195</div> <div>x0.225</div> </div>
CARBON. (a)	MANGANESE. (b)	SILICON. (c)

FIG. 35.—Example 32.

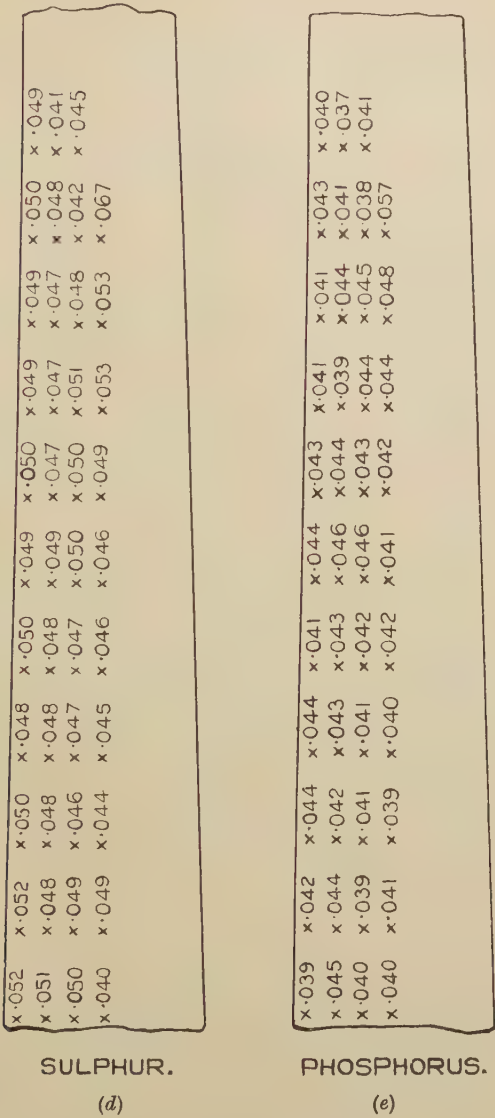


FIG. 35.—Example 32.

- (4) The analyses for silicon result in slightly lower values on the outside portions of Example 32. This phenomenon is not indicated by the analyses on Example 2.

TABLE XVIII.—*Comparison of Example 32 with Example 2 (First Report).*

Example.	Position.							
	A.	B.	C.	D.	E.	F.	G.	X. ¹
	%	%	%	%	%	%	%	%
<i>Carbon.</i>								
32	0·61	0·65	0·62	0·74	0·91+	0·63	0·66	0·63
2	0·52	0·48	0·49	0·53	0·79	0·52	0·54	0·52
<i>Manganese.</i>								
32	0·67	0·64	0·64	0·65	0·68	0·65	0·65	0·66
2	0·84	0·80	0·84	0·82	0·74	0·84	0·84	0·84
<i>Silicon.</i>								
32	0·185	0·225	0·225	0·23	0·225	0·22	0·23	0·21
2	0·21	0·20	0·21	0·21	0·22	0·21	0·22	0·21
<i>Sulphur.</i>								
32	0·049	0·049	0·046	0·053	0·067	0·050	0·048	0·048
2	0·037	0·034	0·032	0·036	0·052	0·040	0·039	0·037
<i>Phosphorus.</i>								
32	0·044	0·041	0·041	0·048	0·057	0·046	0·045	0·044
2	0·036	0·032	0·033	0·035	0·046	0·037	0·039	0·036

¹ The analyses under X in the case of Example 32 are a weighted mean of that of the whole ingot. For Example 2 they are taken from the test sample.

General Observations on Non-Piping or Semi-Killed Steels.

In order to visualise the extent of the segregations in these steels, as well as to aid in comparing them with the piping steels dealt with in the First Report, Tables XIX. to XXIII. have been prepared. These tables give the analytical determinations of carbon, manganese, silicon, sulphur, and phosphorus at the seven standard positions. Table XXIV., giving the percentage ranges of composition for the various elements in each of the ingots studied, is also useful for comparison purposes.

TABLE XIX.—*Carbon.*

Example.	Position.							
	A.	B.	C.	D.	E.	F.	G.	X. ¹
	%	%	%	%	%	%	%	%
24	0.074	0.088	0.061	0.088	0.182	0.109	0.085	0.064
25	0.121	0.115	0.144	0.180	0.412	0.160	...	0.10
26	0.140	0.147	0.145	0.203	0.276	0.169	0.231	0.14
27	0.144	0.111	0.128	0.175	0.237	0.135	0.190	0.13
28	0.17	0.16	0.165	0.20	0.36	0.20	0.23	0.15
29	0.14	0.11	0.10	0.12	0.16	0.12	0.13	0.12
30	0.19	0.15	0.17	0.18	0.32	0.17	0.21	0.19
31	0.13	0.10	0.14	0.16	...	0.15	0.15	0.13

TABLE XX.—*Manganese.*

Example.	Position.							
	A.	B.	C.	D.	E.	F.	G.	X. ¹
	%	%	%	%	%	%	%	%
24	0.371	0.371	0.368	0.385	0.380	0.380	0.377	0.35
25	0.487	0.496	0.475	0.488	0.611	0.483	...	0.49
26	0.568	0.568	0.578	0.559	0.590	0.560	0.558	0.52
27	0.460	0.458	0.462	0.470	0.488	0.450	0.465	0.48
28	0.51	0.52	0.50	0.52	0.60	0.51	0.53	0.49
29	0.65	0.65	0.65	0.64	0.69	0.65	0.65	0.66
30	0.517	0.522	0.495	0.508	0.517	0.506	0.506	0.51
31	0.500	0.495	0.495	0.490	...	0.506	0.500	0.50

TABLE XXI.—*Silicon.*

Example.	Position.							
	A.	B.	C.	D.	E.	F.	G.	X. ¹
	%	%	%	%	%	%	%	%
24	0.014	0.118	0.018	0.008	0.014	0.014	0.010	0.012
25	0.010	0.012	0.012	0.006	0.004	0.016	...	0.012
26	Trace	0.010	Trace	Trace	0.010	0.008	Trace	0.024
27	0.014	0.018	0.014	0.016	0.008	0.012	0.010	0.02
28	...	...	...	...	...	...	...	...
29	...	...	...	...	0.071	...	...	0.03
30	0.063	0.083	0.064	0.061	0.071	0.066	0.068	0.075
31	0.024	0.023	0.023	0.022	...	0.025	0.024	0.024

¹ X is the assumed mean composition of the cast as determined by pit sample or other means.

TABLE XXII.—*Sulphur.*

Example.	Position.							
	A.	B.	C.	D.	E.	F.	G.	X. ¹
	%	%	%	%	%	%	%	%
24	0.018	0.025	0.046	0.056	0.124	0.063	0.070	0.039
25	0.032	0.036	0.047	0.065	0.286	0.044	...	0.037
26	0.020	0.030	0.033	0.056	0.072	0.037	0.058	0.039
27	0.024	0.024	0.026	0.051	0.108	0.030	0.044	0.039
28	0.052	0.048	0.051	0.078	0.150	0.065	0.073	0.059
29	0.112	0.086	0.084	0.094	0.142	0.102	0.103	0.113
30	0.044	0.033	0.032	0.036	0.056	0.041	0.047	0.041
31	0.035	0.029	0.033	0.041	...	0.034	0.038	0.033

TABLE XXIII.—*Phosphorus.*

Example.	Position.							
	A.	B.	C.	D.	E.	F.	G.	X. ¹
	%	%	%	%	%	%	%	%
24	0.006	0.009	0.010	0.011	0.019	0.012	0.013	0.01
25	0.030	0.033	0.037	0.050	0.186	0.041	...	0.036
26	0.017	0.023	0.019	0.033	0.040	0.026	0.035	0.024
27	0.021	0.023	0.027	0.034	0.056	0.027	0.038	0.024
28	0.057	0.053	0.054	0.072	0.138	0.068	0.078	0.061
29	0.108	0.067	0.081	0.089	0.120	0.093	0.099	0.098
30	0.044	0.040	0.036	0.043	0.063	0.046	0.055	0.042
31	0.022	0.016	0.020	0.018	...	0.020	0.023	0.020

¹ X is the assumed mean composition of the cast as determined by pit sample or other means.

Except in the case of silicon, the magnitude of the segregation phenomenon for the various elements of the same order is the same as is found in the piping steels. In the case of Examples 24, 25, and 27, the silicon content shows very large differences throughout the ingot, of a magnitude which is considerably greater than was observed in any of the ingots dealt with in the First Report. In Example 24, the large value for silicon found near the bottom of the ingot may or may not be entirely due to segregation, but, as has been previously mentioned, the condition of the bottom plates may have played some part. In Examples 25 and 27, however, the silicon content near the bottom is not

TABLE XXIV.—Range of Composition in each of the Representative Ingots as obtained by Analyses of Drilled Samples at the Seven Standard Positions.

In preparing this table, the data for position *E* have been excluded in order to be comparable with the results given in the First Report. The figure "range per cent." for each ingot and element is expressed as a percentage of the amount of the element as ascertained by analysis of the corresponding test ingot.

Example.	Weight of Ingot.	Carbon.				Manganese.				Silicon.				Sulphur.				Phosphorus.			
		Test Ingot.	Max.	Min.	Range, %	Test Ingot.	Max.	Min.	Range, %	Test Ingot.	Max.	Min.	Range, %	Test Ingot.	Max.	Min.	Range, %	Test Ingot.	Max.	Min.	Range, %
24	Tons Cwt. 3 1	0.064	0.109	0.061	75	0.35	0.385	0.368	5	0.012	0.118	0.008	917	0.039	0.070	0.018	133	0.01	0.013	0.006	70
25	6 15	0.10	0.180	0.115	65	0.49	0.496	0.475	4	0.012	0.016	0.004	100	0.037	0.065	0.032	89	0.036	0.050	0.030	56
26	7 15	0.14	0.231	0.140	65	0.52	0.578	0.553	4	0.024	0.010	Trace	42	0.039	0.058	0.020	97	0.024	0.035	0.017	75
27	6 15	0.13	0.190	0.111	61	0.48	0.470	0.450	4	0.02	0.018	0.010	40	0.039	0.051	0.024	69	0.024	0.038	0.021	71
28	8 0	0.15	0.23	0.16	47	0.49	0.53	0.50	6	...	...	...	...	0.059	0.078	0.048	51	0.061	0.078	0.053	41
29	3 6	0.12	0.14	0.10	33	0.66	0.65	0.64	1.5	0.03	...	...	...	0.113	0.112	0.084	25	0.098	0.108	0.067	42
30	7 0	0.19	0.21	0.15	32	0.51	0.522	0.506	3	0.075	0.083	0.061	29	0.041	0.047	0.032	36	0.012	0.055	0.036	45
31	7 0	0.13	0.16	0.10	46	0.50	0.506	0.490	3	0.024	0.025	0.022	12.5	0.033	0.041	0.029	36	0.020	0.023	0.016	35

excessive, and the maximum figures are found at a part of the ingot well removed from the base.

As to the general distribution of the elements, there is, as in piping steels, a concentration of the impurities (excepting silicon) in the upper portions of the ingot. There is, however, little indication of negative segregation of carbon, sulphur, and phosphorus in the lower central portion of the ingot, except in the case of Example 29, which behaves exactly like a "killed" steel in virtue of its high sulphur content. There is also a zone of low carbon content in Example 27. All the ingots show evidence of an increased silicon content in the lower middle portion of the ingot, to an even more marked degree than did the ingots dealt with in the First Report. All the ingots reveal V-segregates near the central axis, but they are not so distinct as they are in the piping steels. The non-piping steel does not show Λ -segregate formation; the semi-killed ingots, however, all show this formation. In Example 26, this Λ -segregate is confined to a very narrow zone, whereas in Examples 25 and 27, which were cast on the cold side, it covers a much wider area, or, rather, there appear to be three or more separate inverted cones of segregate in these two ingots.

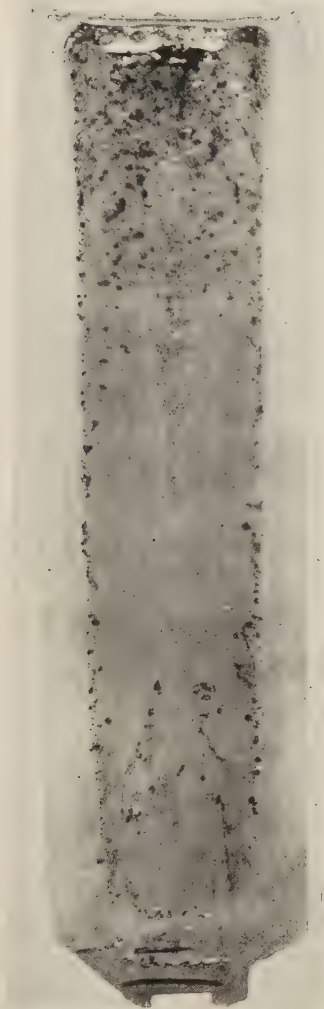
Attention might again be drawn to the relative purity of the outer layer of the ingots cast from steel in a wild or semi-killed condition.

SECTION VI.—*An Interim Report on the Researches at Sheffield University and Glasgow Royal Technical College.*

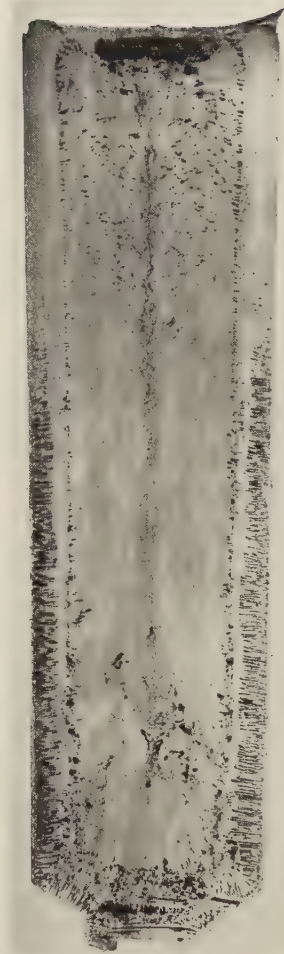
University of Sheffield.

The programme of research work undertaken by Professor Desch, F.R.S., at the University of Sheffield, on behalf of the Committee, includes a determination of the changes of density in steel in the neighbourhood of the melting point, and also of the viscosity of molten steel. The work has been made possible by a grant from the Institute, and by the award of a Carnegie Research Scholarship to Mr. B. S. Smith, M.Met.

A knowledge of the change of the density of steel at the melting or freezing point is of importance for the study of ingot structure.



(f) Sulphur print.



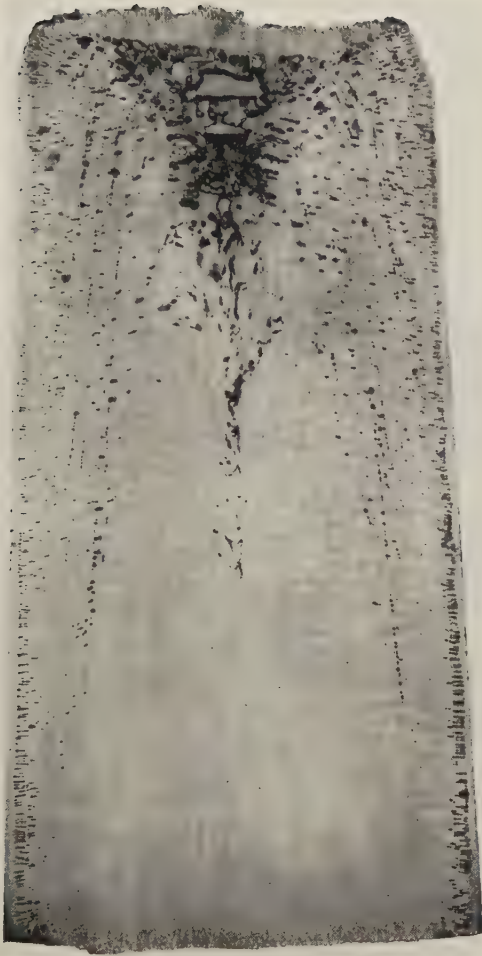
(g) Macro-etching.

FIG. 27.—Example 24.



(f) Sulphur print.

FIG. 28.—Example 25.



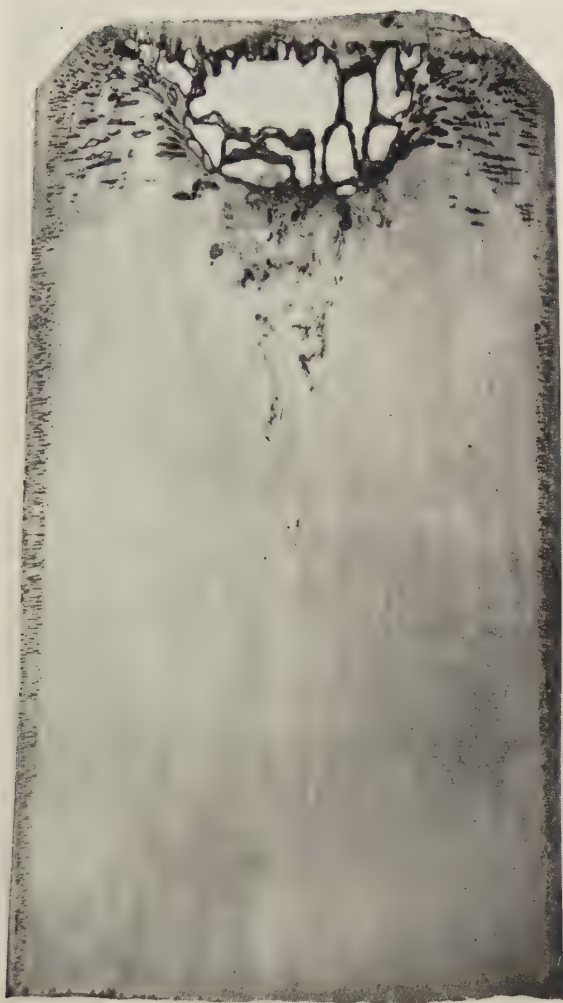
(g) Macro-etching.

FIG. 28.—Example 25.



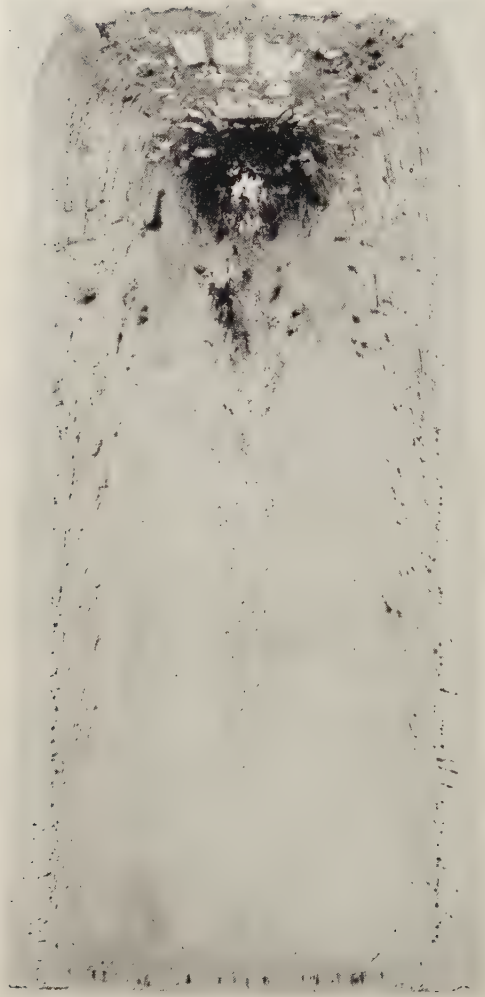
(f) Sulphur print.

FIG. 29,—Example 26.



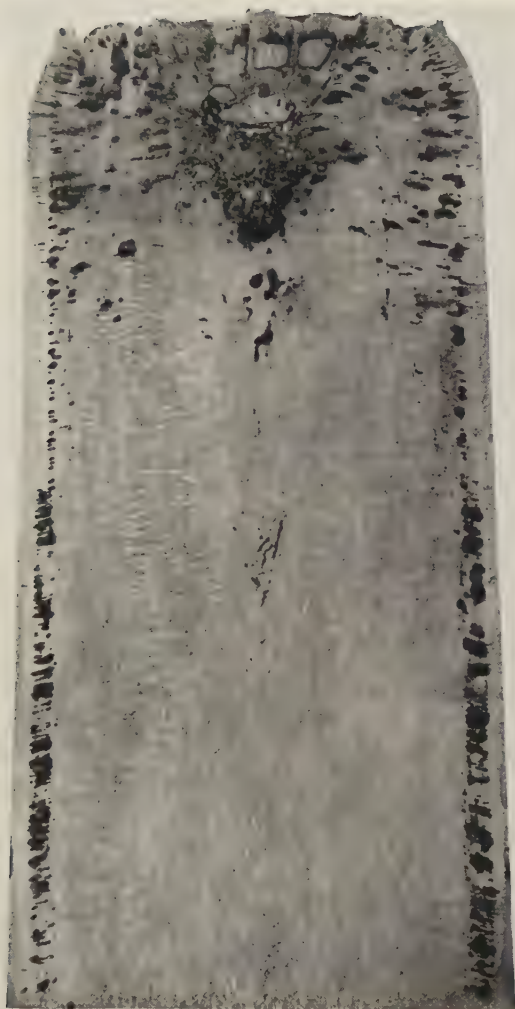
(g) Macro-etching.

FIG. 29.—Example 26.



(f) Sulphur print.

FIG. 30.—Example 27.



(g) Macro-etching

FIG. 30.- Example 27.



(e) Sulphur print.
FIG. 31.—Example 28.



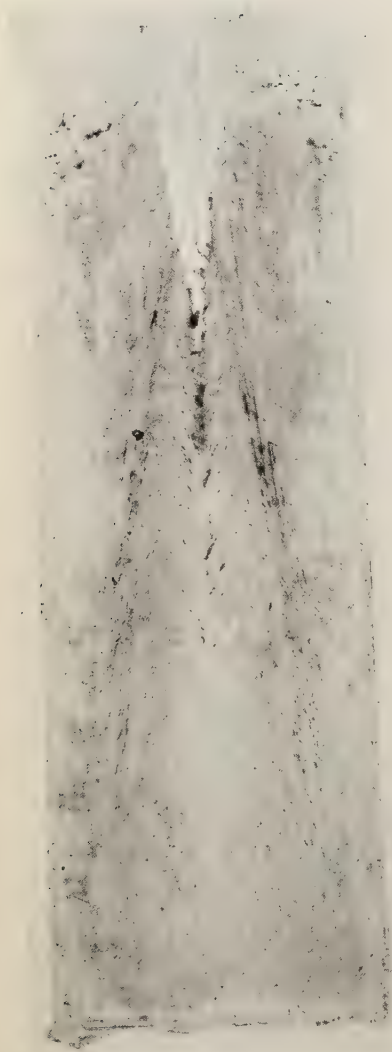
(e) Sulphur print.
FIG. 32.—Example 29.



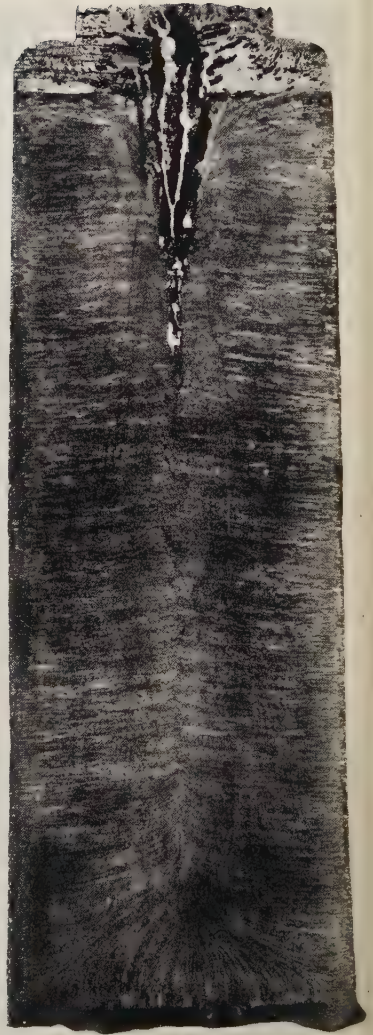
(g) A blowhole into which rising segregate appears to have flowed.



(f) Sulphur print (to a larger scale) of one edge of ingot about one foot from top.



(f) Sulphur print.



(g) Macro-etching.

FIG. 33.—Example 30.



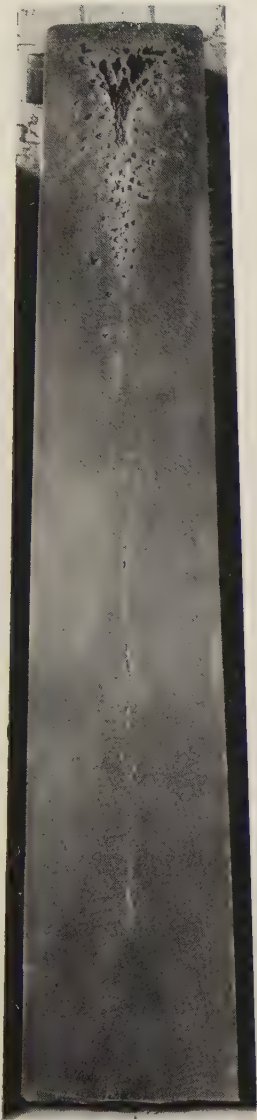
(f) Sulphur print.

FIG. 34.—Example 31.

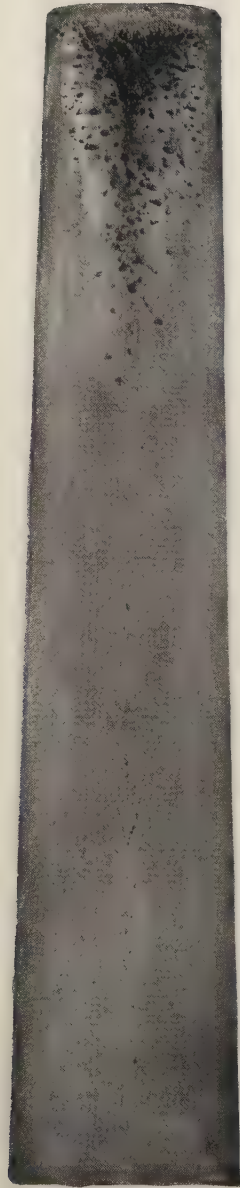


(g) Macro-etching.

FIG. 34.—Example 31.



(f) Polished section.



(g) Macro-etching.

FIG. 35.—Example 32.



Whilst accurate measurements of the changes of density of solid iron up to the neighbourhood of the melting point have been made both by direct measurement and by calculation from X-ray spectra, the few existing determinations of the density of liquid iron and steel cannot be considered final; it is not even known definitely whether liquid steel contracts on freezing like most metals, or whether there is a small expansion such as occurs in a few exceptional instances.

After a number of preliminary experiments a molybdenum-wound furnace has been constructed, and the density is being determined by the method of Archimedes, using a sinker of massive tungsten protected by a suitable refractory.

The furnace is of molybdenum wire wound on an alundum tube. Surrounding the winding, and at a short distance from it, is a cylinder of sheet molybdenum, outside of which is the refractory packing. This consists of a layer of sillimanite enclosed in a thicker layer of kieselguhr. The whole is enclosed in a steel casing. The inert gas (usually nitrogen) employed as an atmosphere is led into the centre and diffuses outwards, this being necessary in order to avoid any water vapour being carried from the refractory packing to the molybdenum wire. A steel tube, provided with windows and with means for introducing the suspension, is screwed to the casing in such a way as to form an upper prolongation of the alundum tube. The sinker is a cylinder of tungsten, carried by a long rod of tungsten and coated with a shell of synthetic sillimanite. Protecting tubes for the tungsten/molybdenum thermocouple have been made in the laboratory from purified zirconia, which retains its shape well after firing at a high temperature and is mechanically strong.

Determinations of the viscosity of molten steel are also to be made. It is known that when the first crystals separate from the molten metal there is an enormous increase in the apparent viscosity, but it is not yet known whether there is any considerable change in viscosity immediately above the melting point. After a consideration of all the possible means of determining the viscosity of liquid steel, the torsional pendulum has been adopted as the only practicable device, and for this purpose again solid masses of tungsten protected by refractory coatings are being used. The upper prolongation of the furnace tube is sufficiently

long to enclose the suspension system of the torsional pendulum, observations of the time of oscillation being made through a window by means of a mirror. Preliminary experiments with molten tin have shown that the method is susceptible of sufficient accuracy. Containing vessels of alundum have been used so far, but experiments are also being made with sillimanite, zirconia, and thoria. It is hoped to present an account of the experiments in the next Report of the Committee.

Royal Technical College, Glasgow.

At the request of the Committee, Professor J. H. Andrew, D.Sc., has undertaken to investigate the freezing and melting ranges of the various types of steel dealt with in the First and Second Reports, and to carry out experiments with a view to gaining information with respect to the formation and possible solubility of sulphide segregates in steel. A grant was made by the Council of the Institute to cover the cost of the necessary apparatus, and a further grant in addition to a Carnegie Scholarship was made to Mr. David Binnie, B.Sc., who was selected to collaborate in the work.

Whilst the freezing and melting ranges of iron-carbon alloys are known with a considerable degree of accuracy, no such data are available for commercial steels. It was thought that before stipulations could be made regarding the correct temperature for teeming, a knowledge of the actual temperature range over which the different steels solidified was not only desirable but necessary. Accordingly, seventeen steels, representing a wide range of composition, were selected for the purpose.

Although the investigation of the liquidus and solidus of the steels selected is not yet completed, it is thought that, since the Council have financed the research, a report on the progress made is due to them and to the Institute.

The investigation at the outset resolved itself into three categories: (1) Selection of a suitable type of furnace; (2) selection of a thermocouple for measuring the temperatures; and (3) selection of a method for measuring the change of state from solid to liquid and *vice versa*.

Design of Furnace.—A horizontal molybdenum-wound electric furnace was designed and constructed in the college. It consists

of a steel outer casing 12 in. in diameter and 24 in. in length. The two steel ends are bored to support an alundum tube 3 in. in diameter. The space between this tube and the casing is filled with a non-conducting material. Inside the alundum tube is placed another tube of the same material 2 in. in diameter wound with molybdenum wire, the annular space between the two tubes always being kept flooded with a mixture of nitrogen and hydrogen, obtained by passing ammonia gas through a cracking train. An inlet and outlet for the gas is provided by means of a tube through the casing.

This type of furnace has worked quite satisfactorily, but requires to be rewound occasionally, on account of the slagging of the refractory. Sometimes it worked well for weeks without rewinding, and at other times a few heats necessitated a complete renewal of the winding and tube.

Thermocouple.—As a thermocouple, two wires of molybdenum and tungsten twisted together to form a couple were tried. This couple was found to be very satisfactory; the temperature/e.m.f. relations were represented by a parabola, and an equation constructed for the curve between the temperature limits of 15° C. and 1200° C. gave on plotting an extrapolated value which agreed perfectly with the actual determined melting point of iron. This couple was used throughout the work.

Selection of Method.—In the first instance, it was decided to measure the change in electrical resistance with temperature, the method adopted being as follows: A small boat of alundum, about 6 in. in length, and having an internal diameter and depth of 4.0 mm. and 5.0 mm. respectively, was made. Into this was fitted a thin section of the solid steel. Intervening spaces between the boat and the sample were filled in with alundum cement. A small hole drilled at each end to take the current lead-in wires, and two holes equidistant from the centre and approximately 5 cm. apart, were drilled to take the p.d. wires. A further hole was made in the centre for the insertion of the thermocouple.

The lead-in and p.d. wires were of molybdenum, and were inserted bare into the metal. In the original experiments these bare wires broke off when the metal became molten, but by using wires of greater diameter this trouble was obviated. The thermocouple was protected by a capillary tube of silica, the end being

made up with alundum cement. In the early experiments two difficulties arose. First, it was found impossible to obtain a true temperature reading with the current passing through the furnace ; and, secondly, owing to unequal heating, the whole length of the sample did not melt at the same time. By cutting off the current momentarily during a temperature reading the first difficulty was overcome. To eliminate the second difficulty a section of about half the length was used. After repeated trials, it was found that the variation in electrical resistance was not sufficient with such a small length to give a sharp indication of the beginning of melting or completion of freezing. This method has therefore been abandoned temporarily in favour of thermal determinations. Objection is often taken to thermal methods for determining the solidus and liquidus, on account of the absence of a distinct inflexion in the curve at the temperature at which liquid just begins to form on heating, that is, the beginning of the solidus, and the temperature at which the last particle of liquid has become solid on cooling. By taking equal volumes of metal for the samples and cooling at similar rates, it has been found that if a curve for a carbon steel be compared with one for pure iron, taken as representing a normal curvature, the deviation of the former curve from the latter gives an excellent criterion of the beginning or the end of any change in state. Moreover, as compared with the resistivity method, this method would seem to be more sensitive to small changes.

Having decided to use thermal methods, the next problem concerned the difficulty of obtaining satisfactory readings of the thermocouple with the current passing through the furnace. It was thought at first that this was due to the refractory acting as a conductor at a high temperature, thereby bringing stray currents into the couple circuit. An inner tube of alundum was then made, which was supported only at the cold ends of the heating tube, and the specimen was placed in the middle of this. This arrangement did not assist in the least, and the trouble was in no way reduced. After much experimenting it was thought that the stray circuits in the thermocouple were due to the thermionic emission of the molybdenum wire at high temperatures (the trouble only began at temperatures above 1400° C.). It was therefore decided to enclose the specimen within a grid, made up of an

alundum tube, around which was coiled molybdenum wire. In the first experiment this was earthed, but the result was no better; then the grid was given a positive charge, and in another experiment a negative charge. Charges of different potentials were tried in each case, but in no way was the trouble decreased. After several weeks of experimenting, this difficulty was finally overcome by making a grid of the following construction: An alundum tube was made, of the same length as the heating tube, the ends of which were of a larger diameter than the middle portions, so that the tube did not make contact with the heated part of the heating tube. Along the length of this were placed 8 wires of molybdenum (it was found that the wires must lie along the tube; coiling the wire around the tube did not obviate the effect). These were bound at their ends with nichrome wire, and the wiring system allowed to remain insulated. By this means any p.d. arising from the thermionic emission charged the grid to a certain potential, which would be constant for any temperature. By allowing the system to remain insulated a back e.m.f. arose, which would then balance the effect. In this manner the trouble was entirely overcome, and temperatures taken with the current on or off were identical. Owing to the sagging of the grid tube in the middle this had often to be replaced.

A curve taken of Armco iron gave exceedingly well-defined points during melting and freezing, and on passing through the δ - γ transformation. On taking a curve of a steel containing 0.5 per cent. of carbon, it was observed that both the heating and cooling curves corresponded to that of the Armco iron, and a micro-examination showed that the carbon had been entirely eliminated.

In the initial experiments small specimens weighing about 30 grm. were completely sealed in an alundum boat, and it was thought that larger specimens might suffer less decarburisation. On using a much thicker and heavier specimen the same effect was, however, observed. Such methods as bubbling the mixed hydrogen and nitrogen gases through volatile oils to enrich them in hydrocarbons did not improve matters in the least. In certain cases the specimens had the appearance of being oxidised on their surface; this was put down as being due to moisture in the gas, and accordingly phosphorus pentoxide, in addition to calcium

chloride and sulphuric acid, was introduced as a drying agent, but this did not remedy matters. Nitrogen from a cylinder was then tried. This was passed over 5 tubes of heated copper and iron turnings to take out the oxygen, and whilst there was some improvement, decarburisation was still apparent, in this case due obviously to the gas not being completely deoxidised. Bubbling the gas through a volatile oil made no difference. The chief drawback to the use of nitrogen was in respect of the life of the furnace, the wire deteriorating rapidly. In order to determine whether the alundum of the crucibles had any effect on the carbon, magnesia was tried as a refractory, but this made no difference. Finally, the difficulty was overcome by using a refractory containing a high percentage of carbon for the crucible and lining this with magnesia. This system has been found to work admirably even when the high hydrogen gas is used.

Notwithstanding that nearly 100 heating and cooling curves have been taken, it is only recently that a satisfactory method for their accurate determination has been arrived at, the investigation up to the present being concerned almost entirely with the methods to employ rather than with actual determinations.

The experimental work on sulphides is not yet in a state at which it would be wise to form definite conclusions. Some interesting observations have been made with reference to the presence of oxides as a constituent of the so-called manganese sulphide segregates.

In addition to the above-mentioned work, an exhaustive micro-examination has been made of several carbon steel ingots. This has revealed some interesting and not unimportant results, which will be reported upon at a later date.

SECTION VII.—*Bibliography.*

The following is included as a continuation of the Bibliography presented in the First Report (*Jnl. I. & S. Inst.*, 1926, No. I. p. 116).

1. F. WÜST and N. KIRPACH: "Determination of Slag in Steel." *Mitteilungen aus dem Kaiser-Wilhelm Institut für Eisenforschung*, 1920, vol. i. pp. 31-38.

(Describes a modification in Schneider's bromine method for the determination of slag inclusions in steel. The carbides, phosphides, and sulphides of iron, and also the manganese sulphides, can be readily dissolved by the new method.)

2. S. SAITO : "The Distribution of Temperature in Steel Ingots during Cooling." *Science Reports of the Tôhoku Imperial University, Sendai*, 1921, vol. x. pp. 305-330.

(An attempt is made at a mathematical solution to the problem of the cooling of steel ingots in their moulds. A formula and equations for heat conduction in an infinite cylinder are given, and similar formulæ and equations relating to finite cylinders are also given.)

3. "Effect of Phosphorus and Sulphur in Steel." *First Report of Committee of American Society for Testing Materials, Proceedings*, 1922, vol. xxii., Part I., p. 94; *Third Report, Proceedings*, 1924, vol. xxiv., Part I., p. 96; *Fourth Report, Proceedings*, 1924, vol. xxiv., Part I., p. 108.

(The First Report deals with the manufacture, test moulds, and data relating to rivet steel containing varying amounts of sulphur from 0.03 to 0.18 per cent. The Third Report discusses the effect of sulphur on endurance properties of rivet steel, and the Fourth Report contains a metallographic study of this material.)

4. F. F. LUCAS : "The Microstructure of Austenite and Martensite." *Transactions of the American Society for Steel Treating*, 1924, vol. vi. pp. 669-691.

(This paper, which describes the structural characteristics of austenite and martensite, contains a description of the application of high-power microscopy to metallography, and the author shows micrographs at magnifications up to 5600 diameters.)

5. "The Physical Chemistry of Steel-Making Processes." A General Discussion held by the Faraday Society and the Iron and Steel Institute, June 1925. *Transactions of the Faraday Society*, 1925, vol. xxxi., Part II.

This Report contains the following papers :

- (1) Sir R. A. HADFIELD : "Physical Chemistry in Steel-Making," pp. 172-175.

(The specific problems relating to the science of steel-making are enumerated as follows : (a) The study of the equilibria of slag reactions ; (b) the mechanism of the origin of slag inclusions and means for their elimination ; (c) the reactions between molten metals and the refractory materials constituting the furnace linings ; (d) the study of the physical properties of slag at high temperature ; (e) a study of the mode of the cooling of ingots.)

- (2) A. McCANCE : "Balanced Reactions in Steel Manufacture," pp. 176-201; *Journal of the West of Scotland Iron and Steel Institute*, 1925-26, vol. xxxiii. pp. 45-52.

(The paper gives results of researches on the iron oxide equilibria, giving calculations of equations applicable to the iron oxide reactions as follows : dissociation of water and carbon dioxides ; reduction by carbon monoxide ; dissociation of iron oxides ; reduction of iron oxides by carbon ; deoxidation of liquid steel ; the reduction of silicon from acid slags ; the formation of inclusions, with some discussion on the relative deoxidising power of Mn and Si, and the influence of deoxidisers on gases.)

- (3) T. P. COLCLOUGH : "A Study of the Reactions of the Basic Open-Hearth Furnace," pp. 202-223.

(A consideration of the order in which the reactions in the bath of metal in the basic open-hearth furnace proceed, their relative

velocities, and the various controlling factors. Figures are given to show the nature of the oxidation due to the gases of the furnace atmosphere. The relative rates of oxidation of carbon and phosphorus are shown to depend primarily on the basicity of the slag. A study of the manganese and ferrous oxide reaction is presented, and data are given to show the close parallelism between the distribution of manganese and the process of desulphurisation.)

- (4) F. T. SISCO : "The Chemical Reactions of the Basic Electric Process," pp. 224-239.

(General details are given of the basic electric process, using cold scrap. The reactions of oxidation are considered in the order in which they occur, and the reactions of deoxidation are then similarly dealt with.)

- (5) J. B. FERGUSON : "Equilibria in Systems Involving Ferrous Oxide," pp. 240-242.

(A study of the chemistry of the systems $\text{Fe}-\text{O}-\text{H}$, and $\text{Fe}-\text{O}-\text{C}$. Most researches show a lack of agreement in respect to the most fundamental points, and the author discusses the relation that the ferrous oxide phase bears to the discrepancies.)

- (6) P. M. MACNAIR : "Slag Reactions," pp. 243-248.

(The essential difference between acid and basic steel practice is given by the equilibrium between slag and lining. The paper deals with the "slag-lining" equilibrium tendencies in both these processes.)

- (7) J. H. WHITELEY : "The Function of Ferric Oxide in Acid and Basic Open-Hearth Slags," pp. 249-254.

(The essential supply of oxygen in the open-hearth process is derived from two sources—namely, the iron oxide added as ore, and the mixture of air and producer-gas passing through the furnace. The paper is concerned with the effect of the oxygen supply from the latter source.)

- (8) A. L. FIELD : "Physico-Chemical Phenomena from Melt to Ingot," pp. 255-267.

(Certain well-established principles of chemical kinetics are applied to the study of the progressive phenomena of oxidation in the hearth of the open-hearth furnace.)

- (9) W. J. REES : "The Micro-Examination of Steel-Making Refractories," pp. 293-295.

(The micro-examination of refractories used in lining steel furnaces, both before and after use, provides information of value in studying reactions which occur within the furnace. Three general methods for the micro-examination of refractories are described.)

6. J. H. HRUSKA : "Life of Large Ingot Moulds." *Iron Age*, 1925, vol. cxvi., Aug. 6, pp. 345-346.

(Analyses of the interior surface of the mould were taken before the first heat, and again after 58 heats were cast: 90 to 98 per cent. of the total carbon in the inner layers of the mould is oxidised to CO_2 , and silicon, sulphur, and phosphorus all show a tendency to increase.)

7. P. BARDENHEUER: "Flakes in Nickel-Chrome Steel." *Mitteilungen aus dem Kaiser-Wilhelm Institut für Eisenforschung*, 1925, vol. vii. pp. 1-15.

(The results of research work on gun tubes of nickel-chrome steel are described. White flakes on the fractured surface are surfaces of hair cracks, and are due to crystal segregation. The cracks are in that portion of the alloy that is the last to solidify between the dendritic branches, which portion, in consequence of its higher content of the alloy elements, is cooled with a martensitic structure, whereas the first portion to solidify is pearlitic. Notes are given as to the avoidance of such flakes.)

8. J. H. HRUSKA: "Time of Pouring Large Ingots." *Iron Age*, 1925, vol. cxvi., Nov. 12, pp. 1305-1306.

(The determination of the exact relationship between the time and the pouring temperature, and practical application of the results to ingot steel, will probably bring about an improvement in the quality of forging steel.)

9. H. D. HIBBARD: "Differences in Open-Hearth Boils." "Ten Types of Open-Hearth Boils." "Open-Hearth Boils of High Vigour." *Iron Age*, 1925, vol. cxvi., Dec. 3, p. 1511; Dec. 10, p. 1605; Dec. 17, p. 1671.

(In these three articles the causes and effects of the action of the bath in the open-hearth process designated as boil are analysed. Ten types of boil are recognised and classified according to degree and violence.)

10. E. C. GROESBECK: "Metallographic Etching Reagents." *U.S. Bureau of Standards*, 1925, *Scientific Paper No. 518*.

(Three etching methods—(a) etching by immersion, (b) electrolytic etching, and (c) heat tinting—were employed to investigate the behaviour towards various etching solutions of constituents commonly occurring in alloy steels and ferro alloys. Etching with acid solutions offers no means of distinguishing between the constituents, but the use of alkaline reagents under oxidising and non-oxidising conditions furnishes the desired differentiation.)

11. C. FRÉMONT: "The Silvery Oval Spot in Certain Transverse Fractures in Rails," *Génie Civil*, 1925, vol. lxxxvii., Oct. 24, pp. 349-351.

(The oval spots in certain transverse ruptures of rails are the result of internal fissuration caused by inclusions, segregation, micro-piping, blow-holes, &c. See Pichard, No. 65.)

12. S. KAYA: "The Solidus Line in the Iron-Carbon System." *Science Reports of the Tôhoku Imperial University, Sendai*, 1925, vol. xiv. pp. 529-536.

(The electric resistance method is used to determine the solidus line in the iron-carbon system. The author's line lies between the curve obtained by Carpenter and Keeling and that of Gustowsky.)

13. M. KUNKELE: "A New Etching Reagent for Determining Sulphide Inclusions in Technical Iron." *Verein deutscher Eisenhüttenleute, Report No. 75*, 1925, 3 pp.; *Chemical Abstracts*, Oct. 20, 1927.

(The composition of the reagent is stated, and photographs of etchings carried out therewith are shown (in the original).)

14. "Report on the Heterogeneity of Steel Ingots." By a Sub-Committee of the Iron and Steel Institute. (With discussion.) *Jnl. I. & S. Inst.*, 1926, No. I. pp. 39-176.

(The Report is divided into the following sections: (1) Introduction; (2) Methods employed in studying the sectioned ingots; (3) Data obtained

from representative steel ingots ; (4) General discussion on the heterogeneity found in ingots ; (5) Bibliography. The Report is accompanied by many photographs of typical ingots, and diagrams illustrating the degree of heterogeneity found in steel ingots, with considerations thereon.)

15. J. H. S. DICKENSON : " A Note on the Distribution of Silicates in Steel Ingots." (With discussion.) *Jnl. I. & S. Inst.*, 1926, No. I. pp. 177-211.

(It is shown that there is a distinct difference between the migration of the silicate particles within a freezing steel and the segregation of C, S, and P, which must be accounted for before the process of solidification within the walls of a chill mould can be satisfactorily explained. Evidence shows that in ingots of carefully deoxidised steel, the percentage of slaggy matter in the form of small globular silicate particles rises to a maximum in the central lower part, precisely where C, S, and P are each reduced to a minimum by segregation. Not only are the silicates in this region greater in amount, but the separated residues include a considerable proportion of globules larger than those normally to be found in any other part of the ingot.)

16. J. H. WHITELEY : " Ghost Lines and the Banded Structure of Rolled and Forged Mild Steels." (With discussion.) *Jnl. I. & S. Inst.*, 1926, No. I. pp. 213-218.

(Evidence is given showing that in certain cases carbon may actually move from one region to another of higher phosphorus concentration. The ghost lines cannot be adequately accounted for as being due to crystallisation of ferrite on non-metallic inclusions.)

17. C. PIERCE : " Making Rimmed Steel." *Paper read before the American Institute of Mining and Metallurgical Engineers*, Feb. 1926.

(Describes practice in the production of rimming steel in the open-hearth furnace.)

18. C. H. HERTY : " Chemical Equilibrium of Manganese, Carbon, and Phosphorus in the Basic Open-Hearth Process." *Paper read before the American Institute of Mining and Metallurgical Engineers*, Feb. 1926.

(The open-hearth process is studied from a physico-chemical point of view by means of experiments made in small laboratory furnaces and 100-ton furnaces.)

19. J. L. KEATES and C. H. HERTY : " Elimination of Metalloids in the Basic Open-Hearth Furnace." *Paper read before the American Institute of Mining and Metallurgical Engineers*, Feb. 1926.

(Results of a test heat made in a standard 100-ton furnace show the manner, proportion, and speed of elimination of each of the several metalloids from the bath, and the changes in composition of the slag during the progress of the heat.)

20. ANON. : " Pouring Ingots by a New Method." *Iron Age*, 1926, vol. cxvii., Jan. 14, pp. 128-129.

(Describes a method of pouring ingots in which a reservoir and float in the mould are used for reducing pipe and blowholes.)

21. J. D. KNOX : " Pouring Device Improves Yield." *Iron Trade Review*, 1926, vol. lxxviii., Jan. 14, pp. 139-142.

(The same device of a refractory float is described.)

22. S. L. GOODALE and P. H. KUTAR: "Non-Metallic Inclusions in Iron and Steel." *Forging, Stamping, Heat Treating*, 1926, vol. xii., Feb., pp. 68-73.
(The properties of non-metallic inclusions and methods of identifying them are discussed.)
23. W. ROGERS: "The 'Shell' Defect in Ingot Moulds." *Foundry Trade Journal*, 1926, vol. xxxiii., Feb. 11, p. 119.
(The causes and prevention of shell defect are briefly discussed, the shell being a thin layer or film of iron which appears in the corners of ingot moulds.)
24. F. F. LUCAS: "High-Power Metallography. Some Recent Developments in Photomicrography and Metallurgical Research." *Journal of the Franklin Institute*, 1926, vol. ccx. pp. 177-216.
(The application of high-power metallography to the study of the structure of a plain carbon steel is described and illustrated.)
25. C. A. F. BENEDICKS: "Some Improvements in High-Power Micrography." *Royal Technical College Metallurgical Club Journal, Glasgow*, 1926, pp. 7-16.
(The technique of high-power micrography is described.)
26. ANON.: "Sulphur in Steel." *Metallurgist*, 1926, Jan. 29, pp. 10-12.
(A review of the present state of knowledge concerning the reactions between sulphur, iron, and manganese, and their effects upon the steel in which they take place. The sulphides which contain normal amounts of manganese appear to be no more injurious than the average non-metallic inclusions, but they should be reduced to the lowest possible amount.)
27. E. C. BAIN: "The Nature of the Alloys of Iron and Chromium." *Transactions of the American Society for Steel Treating*, 1926, vol. ix. pp. 9-32.
(The paper describes the development and preservation at room temperature of the δ -iron solid solution.)
28. G. F. COMSTOCK: "The Treatment of Steel with Ferro-Carbon-Titanium." *Jnl. I. & S. Inst.*, 1926, No. II. pp. 405-415.
(Ferro-titanium, used as a deoxidiser in the ladle, contains about 17 per cent. Ti and 7.5 per cent. C. The advantage of the alloy over aluminium is that it does not make the steel dirty. In effervescing steel it corrects over-oxidation, maintaining the cleanness of the metal. In killed steel it gives more complete deoxidation, and prevents serious segregation. Practice in its use and the results obtained are described.)
29. H. M. BOYLSTON: "Fundamental Reactions Involved in the Making of Iron and Steel." *Fuels and Furnaces*, 1926, vol. iv., Mar., pp. 289-295.
(A discussion of the chemical and physical principles involved in the manufacture of iron and steel. Definitions of cast iron, pig iron, wrought iron, ingot iron, and steel are included.)
30. C. H. HERTY and J. M. GAINES: "The Desulphurising Action of Manganese in Iron." *Paper read before the American Institute of Mining and Metallurgical Engineers*, Oct. 1926.
(Discusses the desulphurisation of pig iron with manganese in the ladle before charging into the open-hearth furnace.)

31. H. D. HIBBARD: "Rimmed Steel and How it is Made." *Iron Age*, 1926, vol. cxvii., June 24, pp. 1778-1780; vol. cxviii., July 15, pp. 142-143; July 22, pp. 214-215.

(A detailed discussion of the manufacture, properties, and uses of rimmed steel. The character of the slags, segregation, and chemical structure of the ingot are likewise discussed.)

32. E. DE LOISY: "The Speed of Elimination of Carbon in the Open-Hearth Furnace." *Revue de Métallurgie, Mémoires*, 1926, vol. xxiii., July, pp. 369-380.

(Discusses the mathematics of the chemical reactions in the open-hearth furnace. Under normal conditions, the speed of decarburisation is proportional at every instant to the amount of carbon remaining in the bath.)

33. P. GOERENS: "Steels of Different Qualities and their Relation to the Methods of Production." *Zeitschrift des Vereines deutscher Ingenieure*, 1926, vol. lxx., Aug. 14, p. 1094; Aug. 21, p. 1129; Sept. 4, p. 1194.

(A general discussion of the methods of production of steels of various qualities. The processes of production should be controlled so as to obtain the ability to produce a certain steel over and over again of unvarying quality.)

34. E. LUBOJATSKY: "Fundamental Factors in the Scientific Production of Particular Kinds of Steel." *Montanistische Rundschau*, 1926, vol. x., May 16, p. 231; June 1, p. 353; June 16, p. 382.

(The series consists of a study of the physical chemistry of steel-making.)

35. F. LEITNER: "Influence of Thickness of Ingot Mould Wall on the Ingot." *Stahl und Eisen*, 1926, vol. xli., May 13, pp. 629-631; English transl., *Forging, Stamping, Heat Treating*, 1926, vol. xii., July, pp. 245-247; Abstr., *Metallurgist*, 1926, June 25, p. 92.

(A report of experiments by Böhler Bros., Austria, to determine the effect of different wall thicknesses in ingot moulds. The class of steel studied was chrome-nickel, and three sizes of ingot were examined—namely, 5½ in. and 9 in. diameter and 10 in. square. Different thicknesses of wall were tried for each type of ingot, and the medium thicknesses, about 40 mm. for the 5½ in., about 42 mm. for the 9 in., and 55 mm. for the 10 in. square ingots, gave the best results as regards the formation of crystallites. The time of solidification was about the same for all thicknesses.)

36. Sir R. A. HADFIELD: "Heterogeneity of Steel Ingots and Sound Steel." *Metallurgist*, 1926, Aug. 27, pp. 119-124.

(A discussion of the necessity for making sound steel. Sound steel is defined as steel which not only does not rise in the mould, but shows distinct settling or piping. The behaviour of steel when cast into small green sand, dry sand, and cast-iron moulds, may furnish tests of the soundness of the steel.)

37. J. H. HRUSKA: "Chemical Analyses of Large Ingots." *Iron Age*, 1926, vol. cxvii., Apr. 15, pp. 1049-1050.

(A number of analyses of steel ingots produced by different processes are tabulated.)

38. D. W. BERLIN: "Some Determinations of the Specific Gravity of Iron and Low-Carbon Steel in a Molten Condition." *I. & S. Inst., Carnegie Scholarship Memoirs*, 1926, vol. xv. pp. 1-15.

(Improvements have been made in the apparatus originally used by the author. The specific gravities of two irons and two steels of different carbon contents were determined, and the mean values of the specific gravity at different temperatures are tabulated. (For the previous Report, see *Carnegie Scholarship Memoirs*, 1924, vol. xiii. p. 129.)

39. F. P. GILLIGAN and J. J. CURRAN: "Macroscopic Examination of Iron and Steel." *Transactions of the American Society for Steel Treating*, 1926, vol. x. pp. 9-30.

(The deep etching method of inspection is described, with a discussion on the merits of the various acid mixtures used in detecting different types of defects.)

40. HAUFE: "The Metallographic Detection of Phosphorus." *Kruppsche Monatshefte*, 1926, vol. vii., Apr., pp. 66-69.

(Comparative trials were made with the following reagents to determine their respective efficacy in revealing the distribution of phosphorus on a steel surface: the reagents of Heyn, Stead, Rosenhain, Le Chatelier, Oberhoffer, and Fry, the composition being stated in each case. Heyn's is the best for ordinary practical work, but if the copper deposit adheres to the surface, then Fry's and Oberhoffer's are preferable.)

41. P. OBERHOFFER: "A Specific Etching Reagent for Silicon in Iron." *Stahl und Eisen*, 1926, vol. lxxvi., Sept. 2, pp. 1191-1192; Abstr., *Metallurgist*, 1926, Dec. 31, p. 192.

(Some remarkable figures were produced on etched surfaces which could be reproduced again and again at will with iodine, but not with any other reagent. The best results were obtained with an alcoholic solution of 1 to 10 parts of $\frac{1}{10}$ -normal iodine solution, with an etching period of 5 to 15 minutes.)

42. K. SCHÖNERT: "The Iron-Oxygen System." *Zeitschrift für anorganische Chemie*, 1926, vol. cliv. pp. 220-225.

(The solubilities of oxygen as ferrous oxide in iron at various temperatures have been determined, and the data are applied to the construction of the equilibrium diagram.)

43. T. C. SUTTON and H. R. AMBLER: "Abnormal Absorption of Gases by Steel." *Transactions of the Faraday Society*, 1926.

(An investigation of the absorption of gases by steel at high pressures and temperatures. It was found that steel would absorb as much as 30 c.c. of gas per gm., which is firmly retained at temperatures below 600°.)

44. K. IWASÉ: "Occlusion of Gases by Metals and Alloys in Liquid and Solid Phases." *Kinzoku no Kenku*, 1926, No. 3, p. 119.

(The quantity of gases which can be absorbed or evolved by metals at high temperatures without causing chemical reactions was determined.)

45. P. OBERHOFFER: "Determination of Oxygen in Steel." *Stahl und Eisen*, 1926, vol. xlv., Aug. 5, pp. 1045-1049.

(Describes improvements in apparatus and procedure in determining oxygen in iron, by the hydrogen, the hot extraction, and the residue methods.)

46. P. KLINGER: "Determination of Gases in Iron and Steel." *Stahl und Eisen*, 1926, vol. xlv., Sept. 16, p. 1245; Sept. 23, p. 1284; Oct. 7, p. 1353.

(Experiments were made for the purpose of testing the results obtained by previous workers in the determination of gases in iron and steel. Ten methods were followed, two of which were by hot extraction under vacuum. The other eight were chemical solution or conversion methods.)

47. H. D. HIBBARD: "Controlling Segregation in Steel." *Iron Age*, 1926, vol. cxviii., Dec. 2, pp. 1546-1548.

(The main factors affecting segregation in steel are discussed.)

48. J. H. G. MONYPENNY: "The Influence of Steel Ingot Defects in Subsequent Manufacture." *Paper read before the Manchester Metallurgical Society*, 1926; *Metal Industry*, 1926, vol. xxix., Dec. 10, pp. 565-566.

49. R. H. GREAVES: "Hair-Line Cracks in Nickel-Chromium Steel." *Metalurgist*, 1926, Nov. 26, pp. 167-171.

(A report of an investigation by the Research Department, Woolwich, on the occurrence and distribution of hair-line cracks in Ni-Cr steels, with a review of the various opinions of previous investigators on the cause and formation of such cracks.)

A summary and criticism of Bardenheuer's paper (see No. 7) is given.)

50. J. A. JONES: "The Influence of Molybdenum on Medium Carbon Steels containing Nickel and Chromium." *Research Department, Woolwich*, 1926, *Report No. 67*.

(The thermal critical ranges, microstructure, and mechanical properties of a number of Ni, Cr, and Ni-Cr steels containing molybdenum were investigated. Molybdenum has a pronounced effect in reducing or, in some cases, completely eliminating the susceptibility of the steel to temper-brittleness.)

51. V. N. KRIVOBOK: "Dendritic Crystallisation and Grain Formation in Steels." *Transactions of the American Society for Steel Treating*, 1926, vol. x, pp. 758-781.

(Results are presented of observations on the secondary crystallisation of steels. Dendritic segregation is not the sole cause of defective steel, and a pronounced dendritic structure is not sufficient reason for the rejection of the steel.)

52. M. BALLAY: "The Ludwig-Soret Phenomenon in Alloys." *Comptes Rendus*, 1926, vol. clxxxiii, pp. 603-611.

(Experiments by the author show that the Soret effect is clearly established for liquid and solid alloys.)

53. K. POPPE: "Chromium-Nickel Electro-Steel." *Zentralblatt für Hütten- und Walzwerke*, 1926, vol. xxx, pp. 91-94.

54. A. L. FIELD : "Solidification of Steel in the Ingot Mould." *Transactions of the American Society for Steel Treating*, 1927, vol. xi., Feb., pp. 264-276, 338.

(The subject is treated mathematically. In the case of steel poured at its melting temperature, the maximum rate of solidification is shown to be inversely proportional to the square root of the elapsed time measured from the moment of contact between liquid steel and mould wall. The distance through which solidification progresses is directly proportional to the square root of the elapsed time.)

55. J. D. GAT : "Ideal versus Commercial Steels." *Forging, Stamping, Heat Treating*, 1927, vol. xiii., Feb., p. 38; Mar., p. 79; Apr., p. 124.

(Ingot defects, such as piping, segregation, liquation, banding, and porosity, are considered in connection with open-hearth furnace practice.)

56. H. M. BOYLSTON : "Importance of Manganese in the Steel Industry." *Paper read before the American Institute of Mining and Metallurgical Engineers*, Apr. 1927.

(The function of manganese in steel-making and its influence on the properties of steel are briefly discussed.)

57. H. THIELMANN and A. WIMMER : "The Internal Friction (Viscosity) of Liquid Pig Iron." *Stahl und Eisen*, 1927, vol. xlvii., Mar. 10, pp. 389-399.

(To determine the viscosity of liquid iron the vibration method was tried, using a disc of a special kind of porcelain. An open bath was first tried, but, owing to the formation of oxide films on the surface of the metal, the bath was afterwards entirely closed in. The disc form of bob was then abandoned and a hollow porcelain cylinder filled with the liquid metal was used. A bifilar suspension was adopted for the pendulum, making it capable of being raised and lowered and of having a slight rotary motion imparted to it.)

58. H. J. VAN ROYEN and E. AMMERMAN : "Methods for the Detection of Sulphur in Polished Steel Sections." *Stahl und Eisen*, 1927, vol. xlvii., Apr. 14, pp. 631-632.

(There are two well-known processes for revealing distribution of sulphur in steel : (1) The Heyn and Bauer method : A silk cloth moistened with an acid solution of mercuric chloride is applied to the polished surface and allowed to remain four or five minutes. The segregates of sulphur and phosphorus are discriminated by their black and yellow colour. (2) The Baumann or silver bromide process : This has the disadvantage that the phosphorus as well as the sulphur segregation is printed dark, and, though it affords a good picture of the degree of segregation, it may be deceptive with regard to the actual quantity of either of those elements. The Heyn-Bauer process may be modified by the use of gelatine paper obtained by fixing and washing the silver bromide from bromide paper. The gelatine paper is then soaked in the acid solution of mercuric chloride and pressed on the steel surface. The chemical reactions are the same as in the Heyn-Bauer process, the black regions corresponding to the sulphide inclusions, while the phosphorus segregates are shown bright yellow.)

59. J. D. GAT : "Theory to Explain Abnormal Steel." *Iron Age*, 1927, vol. cxix., Apr. 21, pp. 1142-1144.

(Non-hardenability is found to be due to an excessive amount of oxygen in steel.)

60. A. W. PORTER: "The Soret Effect." *Transactions of the Faraday Society*, 1927, vol. xxiii. pp. 314-316.

(An accurate analysis of the meaning of the Soret effect is made. It is conclusively shown that the concentration is proportional, not to the absolute temperature, but to the square root of that temperature, which reduces the amount of change to be expected—e.g. a difference of temperature of 100° C. in zones of a liquid at an average temperature of 1550° C. would produce a difference in concentration of only 5 per cent., which change in the concentration of impurities in steel is practically negligible.)

61. C. C. TANNER: "The Soret Effect." *Transactions of the Faraday Society*, 1927, vol. xxiii. pp. 75-95.

(The author describes an optical method for studying the Soret effect. His results practically confirm those of previous investigators. The magnitude of the fractional change of concentration per degree found by the optical method is, however, always numerically greater than that found by the conductivity method.)

62. J. L. HAUGHTON: "Alloys of Iron Research. Part VIII.—The Constitution of Alloys of Iron and Phosphorus." *Jnl. I. & S. Inst.*, 1927, No. I. pp. 417-434.

63. W. GROSSE and W. DINKLER: "An Improved Calorimeter for Determining the Specific Heats of Metals, Oxides, and Slags." *Stahl und Eisen*, 1927, vol. xlvii., Mar. 17, pp. 448-453.

(A metal calorimeter for determining the temperature-heat-content curves of metals, oxides, or slags is described and illustrated.)

64. A. WÜSTER and E. PIWOWARSKY. "A New Method for Determining the Gas Content of Liquid Metals." *Stahl und Eisen*, 1927, vol. xlvii., Apr. 28, pp. 698-702.

(The new apparatus consists in the main of a steel container holding about 2.2 kg. of liquid steel into which samples can be drawn by suction direct from the furnace bath. When filled by suction, the vacuum causes the gases to evolve, and they are removed by a mercury pump to a gas collector and analyser.)

65. L. PICHARD: "The Internal Fissuration of Rails with an Oval Spot." *Génie Civil*, 1927, vol. xc., Jan. 29, pp. 118-123.

(Hypotheses are given as to the origin of various types of such spots. See C. Frémont, No. 11.)

66. K. HONDA and H. ENDO: "Magnetic Determination of the Solidus and Solubility Lines in the Iron-Carbon System." *Science Reports of the Tôhoku Imperial University, Sendai*, 1927, vol. xvi. pp. 235-244.

(These lines were determined from the magnetic susceptibility/temperature curve. The solidus line coincides closely, and the solubility lines exactly, with those obtained by other investigators.)

67. K. HONDA and H. ENDO: "The Magnetic Susceptibility of the Iron-Carbon Alloys at High Temperature and the Equilibrium Diagram of the System." *Science Reports of the Tôhoku Imperial University, Sendai*, 1927, vol. xvi. pp. 627-637.

68. J. D. GAT: "Physical and Chemical Structure of Ingots." *Blast-Furnace and Steel Plant*, 1927, vol. xv., May, pp. 207-211.

(The mechanism of solidification is discussed, and defects in ingots due to segregation, liquation, piping, porosity, and banding are considered. Grinding the surface of the steel and etching in boiling concentrated HCl usually reveals the segregation of areas containing higher carbon or inclusions because of their greater corrodibility.)

69. A. WIMMER: "Macro- and Microstructure of Blowhole Segregation in Steel." *Stahl und Eisen*, 1927, vol. xlvii., May 12, pp. 781-785.

(The occurrence and formation of blowholes in steel are considered, with reference to the composition and microstructure as revealed by different etching reagents. In general, it would appear that sulphide and oxide segregations are mainly responsible for the formation of blowholes, as the sulphide inclusions around the blowholes are much more numerous than in other parts of the metal.)

70. P. GOERENS: "Special Steels and their Relation to the Production Processes." *Kruppsche Monatshefte*, 1927, vol. viii. pp. 1-8, 25-48; Abstr., *Metallurgist*, 1927, May 27, pp. 75-78.

(The properties of special steels, as distinct from ordinary commercial steels, are discussed. In particular, reference is made to the occurrence of inclusions, the mode in which they are formed, and their influence on the quality of the steel. Closer co-operation between users and manufacturers in the study of the metallurgical problems is advocated.)

71. P. OBERHOFFER: "Oxygen in Steel." *Revue Technique Luxembourgeoise*, 1927, vol. xix., July, pp. 99-111; *Zeitschrift des Vereines deutscher Ingenieure*, 1927, vol. lxxi., Nov. 5, pp. 1569-1576.

(In searching for a suitable method of analysis for the determination of oxygen, the hydrogen reduction method was found inaccurate. The method of reduction by carbon and the volumetric measurement of CO and CO₂ were more promising, and a vacuum extraction apparatus was eventually developed. Four ingots of 1.2 up to 4.7 tons were cast from the same charge in order to study the segregation of the carbon, silicon, phosphorus, and oxygen. Oxygen appeared under the conditions to be the least segregated. The effect of small percentages of oxygen on the properties of steel is shown to be very marked.)

72. P. OBERHOFFER and E. AMMANN: "Note on the Estimation of Oxide Inclusions in Pig Iron and Steel." *Stahl und Eisen*, 1927, vol. xlvii., Sept. 15, pp. 1536-1540.

(The bromine method for determination of iron and manganese oxide is not satisfactory. The present article deals mainly with the estimation of silica, silicates, and alumina. Results of SiO₂ and Al₂O₃ determinations in acid and basic steel are given, and comparison is made with results by other methods.)

73. P. OBERHOFFER, H. J. SCHIFFLER, and W. HESSENBRUCH: "Oxygen in Iron and Steel." *Archiv für das Eisenhüttenwesen*, 1927, vol. i. pp. 57-68; *Stahl und Eisen*, 1927, vol. xlvii., Sept. 15, pp. 1540-1543.

(On the primary etching of electrolytic iron and iron oxide melted in vacuo, a distinct grain segregation was observed, which is attributed to oxygen present in solid solution. Secondary etching showed, in overblown

steels, large grain inner crystal structure of ferrite and large variation in the number of inclusions from grain to grain. In general, a steel with high oxygen content showed an uneven, indistinct structure.

Forging tests to determine the influence of oxygen on properties of steels gave distinct sliding or woody fractures, which were attributed to oxygen segregation. Other effects of oxygen are discussed.)

74. C. BENEDICKS and H. LÖFQUIST: "The Iron-Oxygen System." *Zeitschrift des Vereines deutscher Ingenieure*, 1927, vol. lxxi., Nov. 5, pp. 1576-1577.

(A diagram is given, which is mainly based on data given by Tritton and Hanson. The solubility of oxygen is 0.21 per cent. in liquid iron, 0.05 per cent. in solid α -iron, and rather higher in γ -iron. Fundamentally, the diagram is considered to be correct, although some of the curves may be displaced considerably.)

75. J. D. GAT: "Oxygen in Steel and Non-Hardenability." *Blast-Furnace and Steel Plant*, 1927, vol. xv., June, pp. 271-274, 279; *Transactions of the American Society for Steel Treating*, 1927, vol. xii., Sept., pp. 376-413.

(Experiments were made to prove the harmful influence of oxygen in steel. The phenomenon of non-uniform hardening is attributed to the presence of oxygen dissolved in the steel, the oxygen forming possibly a compound, iron-carbon-oxygen.)

76. W. EILENDER and W. OERTEL: "Influence of Oxygen on the Properties of Steel." *Stahl und Eisen*, 1927, vol. xlvii., Sept. 22, pp. 1558-1561.

(The influence of oxygen in steel is very important, and precise numerical values of its influence have been determined for many types of steel. In the case of Ni-Cr steel, annealing brittleness is traceable to oxygen content.)

77. P. OBERHOFFER and H. SCHENCK: "Theoretical and Practical Investigations on the Deoxidation of Iron with Manganese." *Stahl und Eisen*, 1927, vol. xlvii., Sept. 15, pp. 1526-1536.

(Deoxidation in practice has shown that the complete removal of oxygen is only possible by extraordinary measures, such as the treatment of the steel *in vacuo*. The total oxygen can only be accurately determined by hot extraction.)

78. H. D. HIBBARD: "Parallel between Sulphur and Oxygen in Steel Metallurgy." *Fuels and Furnaces*, 1927, vol. v., Nov., pp. 1445-1447.

(The action of sulphur and oxygen in the manufacture of steel is discussed.)

79. VON GÖLER and G. SACHS: "The Genesis of the Structure of Cast Ingots." *Zeitschrift des Vereines deutscher Ingenieure*, 1927, vol. lxxi., Sept. 24, pp. 1353-1357.

(The manner in which the crystal growth is modified by changing the form of the mould, and the effect of this on piping and segregation, are illustrated and discussed.)

80. J. H. WHITELEY: "Hair-Cracks in Steel Rails." *Transactions of the American Society for Steel Treating*, 1927, vol. xii., Aug., pp. 208-220, 234.

(Gives the results of an examination of a number of basic steel rails, many of which, on straightening, broke, showing a grey spot in the crystal-line fracture, the causes of which are discussed.)

81. A. C. FIELDNER: "Co-operative Research in Ferrous Metallurgy, and the Problem of Inclusions in Steel." *Proceedings of the Engineers' Society of Western Pennsylvania*, 1927, vol. xliii., June, pp. 221-242.

(The programme of research on inclusions in steel to be undertaken by the U.S. Bureau of Mines, the Carnegie Institute of Technology, and the Metallurgical Advisory Board, is set out, and the organisation of the research and facilities for it are described.)

82. C. H. HERTY: "Fundamental Research in Steel Manufacture." *Transactions of the American Society for Steel Treating*, 1927, vol. xi., June, pp. 899-914, 1015.

(The problems encountered in steel-making are classified, with particular reference to the formation and elimination of non-metallic inclusions.)

TEXT-BOOKS.

- P. OBERHOFFER: "Das technische Eisen: Konstitution und Eigenschaften." 8vo, pp. 598, with 610 figures in the text. Second edition. Berlin, 1925: Julius Springer.
- E. HEYN: "Physical Metallography." 8vo, pp. 40. Transl. from the German by M. A. Grossmann. New York, 1925: John Wiley & Sons, Inc.; London: Chapman and Hall, Ltd.
- J. M. CAMP and C. B. FRANCIS: "The Making, Shaping, and Treating of Steel." 8vo, pp. 1142 + lxi, with 346 illustrations. Fourth edition. Pittsburgh, 1925: Carnegie Steel Company, Bureau of Technical Instruction.

PATENTS.

- E. LÜNGEN: "Ingot Moulds." Patent 270363. Oct. 22, 1926. *Illustrated Official Journal*, 1927, June 29, p. 2756.

(Runners for ingot moulds are provided with enlarged cavities near the mould to collect impurities from the steel and feed the shrinkage head. These enlarged cavities may be formed in moulded blocks, and may connect adjacent conduit blocks or a conduit to a mould by openings.)

- Sir C. A. PARSONS and H. M. DUNCAN. "Improvements in, or Relating to, the Casting of Ingots." Patent 278032. Sept. 29, 1927.

(The object of the invention is to procure ingots of greater homogeneity and soundness. The invention consists in a process of casting steel ingots comprising pouring the molten metal into a mould having its longitudinal dimensions greater than its vertical, thick refractory material covering the sides of said mould and a bottom chill of large dimensions, preferably of metal, preheating the mould to a high temperature of the order of molten steel before pouring the metal therein, and continuously supplying heat to the upper surface of the molten metal after casting, so that the upper layer is the last to solidify.)

DISCUSSION.

Dr. W. H. HATFIELD (Member of Council), in presenting the Report, said the Committee felt that with its presentation it had published the results of a very systematic and careful study of the various general types of ingots—a study which was really necessary to put on record the state of the art at the present time. The ingots reported on were representative of good practice, but they were not selected ingots, superior to ordinary good practice; he wished to emphasise that in no case were they superior ingots such as might be achieved only as a matter of luck in the course of manufacture.

In its First Report the Committee examined killed steel—carbon steel—ingots by various methods, and it then, in Section IV. of that Report, sought to give a picture of what happened when an ingot froze. The main criticism levelled at that First Report was that the Committee was ill-advised in attempting to give, or at any rate was extremely unsuccessful in giving, an adequate picture of what happened. On behalf of the Committee, he had to endorse that view in some measure. The Committee had, of course, learned quite a lot about ingots as it pursued its inquiries, and now, after 4 years' work, it was much more modest about its ability to explain the various phenomena than it was when it commenced its investigations.

[Dr. HATFIELD then briefly summarised the contents of the Report.]

Dr. W. ROSENHAIN, F.R.S. (National Physical Laboratory), said that Dr. Hatfield and his Committee were to be congratulated and thanked most sincerely for the work they had done. They had provided a mass of facts which were not easy to secure. They represented a very large amount of work of an expensive and difficult character, which, he suggested, only a Committee which was fortunate enough to secure the free co-operation of a number of steel firms could have produced.

Turning to the Report itself, one had to realise in reading it the difficulties which existed in work of the kind described and the limitations which the Committee, perhaps wisely, imposed upon itself. The method employed was almost inevitably what he called the "natural history" method; the work could hardly be described as experimental research, it was more in the nature of detailed observation. The Committee, almost of necessity, had to take the ingots produced in the steelworks and examine them; and, as Dr. Hatfield said, it had done so with a view to presenting the present state of the art.

While he was most ready to accept the assurances of Dr. Hatfield and the Committee that, to the best of their knowledge and belief, the

ingots chosen were representative ones, he thought it must be remembered that neither the Committee nor anyone else could possibly say within what degree of accuracy they were really representative; in other words, how uniform from ingot to ingot was the distribution of the impurities. He might be told that the collective wisdom and experience of the Committee enabled it to say that it was satisfied on that point; but when it came to a matter of data, upon which, he hoped, scientific deductions were ultimately to be based, something more than that was required. He knew it was asking for a good deal, but the Committee, with the immense resources at its disposal, might perhaps be able—not in regard to all the types of ingots, but in regard to a few—to section not one ingot of a kind, or even two made under different conditions, but half a dozen made as nearly as possible exactly alike. It could then say, with that scientific frankness which characterised its Reports, exactly how nearly alike those half-dozen were. One would then be in a better position to know what was really the fundamental fact about the distribution of impurities, and what was—to use a word for the want of a better—accidental. By “accidental” he meant due to those conditions and factors which were not known or which it was not possible to control.

Two facts appeared to stand out as generalisations, which might be drawn from the Report without going any further than the Committee itself had really gone. One was the point to which Dr. Hatfield referred in presenting the Report, the relative non-segregation, or the limited extent to which segregation occurred, in regard to the metallic elements, manganese, nickel, and chromium. That, perhaps, was not very surprising. The atoms of those metals were so similar to the atoms of iron itself that the forces which tended to separate them must be smaller than in the case of the metalloids like carbon, phosphorus, and sulphur. Nevertheless, the demonstration of that fact was important and valuable.

The second, also referred to in the Report and by Dr. Hatfield, was the very marked influence of the liberation of gases during solidification of the ingot on the arrangement of the segregates. That effect one would perhaps have anticipated, but in such matters anticipation had not much value; one wanted to know, and the Report gave the requisite knowledge. One could conclude that the presence or absence of currents within the metal, as influenced by the movement of gas as solidification progressed, played an important part in determining the distribution, at any rate of the carbon, sulphur, and phosphorus.

There were one or two other minor points to which he wished to refer. One of them was a suggestion for further work which the Committee might undertake. Some years ago the President described before the Institute a process of rolling an ingot which was not completely solid internally. That was sometimes done unintentionally in steelworks. He had seen examples of it, and when an ingot of that kind was afterwards cut and etched, a white patch was found in the

centre of the steel. No doubt the President was quite familiar with that fact. That was a very peculiar phenomenon, about which there had been a good deal of speculation, but it implied a remarkable form of segregation, and it also raised another question which he wished to put to the Committee: Was the map of the segregate that one got in those ingots (and particularly in large ones) influenced when the ingots were allowed to remain in the soaking pit? It would be of interest to know how far diffusion, in the solid and semi-solid state, either accentuated or tended to wipe out those differences of composition. His own impression was that so far as the metallic elements were concerned it would tend to wipe it out; the segregation, already small, of the metallic elements would probably tend to diminish; but whether or not the segregation of sulphur and phosphorus would diminish was a point of great interest, both theoretically and practically, because it would give information as to whether or not those elements were capable of diffusing through solid iron. One might expect the phosphorus to do so, because a definite solid solubility of phosphorus and iron had been established; but in the case of sulphur nothing was known, and light on that point would be extremely interesting.

Then, again, further to expand the programme which he was venturing to suggest for the consideration of the Committee, an investigation of the question of fluid compression, particularly in the Harmet process, would be of interest. At the top of the ingot a highly segregated substance was squeezed out, and that was very instructive as throwing light on the processes which took place in the segregation.

He wished to say a word or two about the two end sections of the Report. He felt a little diffidence in discussing them, because they related to incomplete work, and his sympathy was rather with the authors, who had felt obliged to make some statement at the present stage of their investigation. With regard to the determination of the liquidus and solidus of commercial steels, a good deal of work on that subject had been done in his laboratory. It had not been published in the form of a paper, because the results at that time were of a somewhat negative character; but references, sometimes in some detail, had been made to the work in the Annual Reports of the Laboratory. It was found that the attempt to determine the solidus by the electrical resistance method had to be abandoned, for the very reason that Professor Andrew had rediscovered, namely, that the effect on the electrical conductivity was too small. His laboratory also came across, and to some extent got over, the difficulty of rapid decarburisation at high temperatures, to which reference had been made. When one was carrying out work from the point of view of pure research, one was at a great advantage compared with a man who had to try to determine a point for a given steel; one could be content to determine the composition of the steel after one had finished with it, instead of having to start and finish with the same material.

There was no difficulty at all about the determination of the liquidus;

it was perfectly possible to use platinum thermocouples at those temperatures and obtain satisfactory readings of the liquidus with them. The publication of the iron-phosphorus diagram before the Institute the previous year gave definite evidence that that could be done with all the necessary accuracy—an accuracy as great as that with which the temperature scale was known in those high ranges.

Those were quite small, incidental remarks, and he wished it to be understood that he was making them solely from the point of view of suggesting that a little consultation and co-ordination of activities of that kind would sometimes save a good deal of unnecessary trouble.

It was difficult to discuss so large a document as the present Report in detail or with much effect. He thoroughly commended the wisdom of the Committee in refraining from theorising on the matter at the present stage. Differences of opinion were bound to exist, and although a Committee might agree on facts, theories were often matters of individual opinion. Quite apart from what the future might have in store in the way of scientific explanations of the principles which govern the phenomena of solidification, what he would very much value, as a busy man who had not time to read and consider every detail, was a summary giving a bird's-eye view of the facts. Naturally, such a summary could not be an accurate statement of all the facts; if it were, it would be as long as the original Report. A pamphlet of perhaps a dozen pages, in which the leading facts were clearly summarised, would meet the case.

Professor C. H. DESCH, F.R.S. (Member of Council), speaking on behalf of those members of the Committee who were not connected with the steel manufacturers, wished to say how greatly the industry and science of metallurgy were indebted for the work the steel manufacturers had done. Dr. Hatfield had remarked that the ingots were not specially selected, but represented general practice. One could make that more precise by saying that the ingots represented the regular practice of firms of good standing. The production of the ingots, the sacrificing of them by cutting them up, the grinding and surfacing for preparing macro-etchings and sulphur prints, had been an enormously costly business, and that cost had been borne entirely by the steel industry.

Dr. Rosenhain had referred to the experimental work now in hand under the charge of Professor Andrew and himself, and had pointed out some of the difficulties. Naturally, the section on that work contained at the end of the Report was merely in the nature of an indication that the research was going on; the publication of the results would have to be postponed awhile. The carrying out of such experiments was a long and tedious business.

Dr. A. McCANCE (Glasgow) said he had read the Report with pleasure, but found some little difficulty in discussing it owing to the enormous

amount of information included in it. Facts did not lend themselves to discussion, unless one was prepared to put up an alternative array of counterfacts. The value of the Report was beyond question. In general the information regarding the heterogeneity of steel ingots disclosed in the Report was, he thought, already known to the makers of the better classes of steel, but the publication of the Report was most valuable, because the authority of the investigators behind it would place on a definite footing things which had been generally known and frequently misunderstood.

One of the points to which he wished to draw attention concerned ingots Nos. 17 and 18, in regard to which the Committee made comparisons between the degree of segregation of a small 15-cwt. ingot and a larger ingot of 57 cwt. They said the facts showed at once a distinctly higher degree of segregation for each of the elements in the case of the larger ingot; but if one looked at Table III. the figures given hardly bore out that contention, except in the case of sulphur. In the case of sulphur, the range between the maximum and minimum content was certainly greater in the larger ingot than in the smaller one, but for carbon and phosphorus he hardly thought the figures did show a distinctly higher degree of segregation. He admitted that the length and the distinctness of the segregation lines in the sulphur prints did indicate that the more minute segregation was of a more intense kind in the larger ingot, but he thought the Committee would be wise to draw special attention to that, and to modify somewhat the statement of its views.

The next two ingots, Nos. 19 and 20, brought out what he thought was rather an illuminating point. The ingots were of the same size, and practically the only difference between them was the rate of teeming. The percentage variations in Table XVI. demonstrated that No. 19, which was cast at a much slower rate than No. 20, showed a remarkably less degree of segregation, although they were both out of the same charge and, so far as indications were disclosed, all the other conditions were the same.

That question of the comparison of ingots from the same charge was one which he should like the Committee to continue to examine, because it was only in that way that some of the underlying principles governing the control of segregation would be understood.

He did not wish to ask for a great deal of further work, but there were so many suggestive paragraphs in the Report that one really could not help it. On p. 419, for instance, two very important matters were dismissed in a sentence. The Report said: "The correct taper is difficult to decide, as it depends on the rates of cooling at the freezing temperature in the various parts of the ingot. The taper should be such as to make possible efficient feeding of the body of the ingot." The last sentence was a pious expression of opinion, hardly worthy of the spirit of investigation which animated the rest of the work, and he would like it to be connected later with a detailed series of experiments,

showing those who were going to make and design ingot moulds what was really the best taper to diminish segregation. He gathered indeed from that paragraph that the Committee had shelved the matter, and that the sentence "The taper should be such as to make possible efficient feeding of the body of the ingot" represented the fruit of their collective wisdom on ingot taper. But he did hope that that was not the case, and that the Committee would give further information on that important topic.

Mr. J. G. PEARCE (Birmingham) said that the Report hinted in a very delicate way at the lack of information on the properties of cast

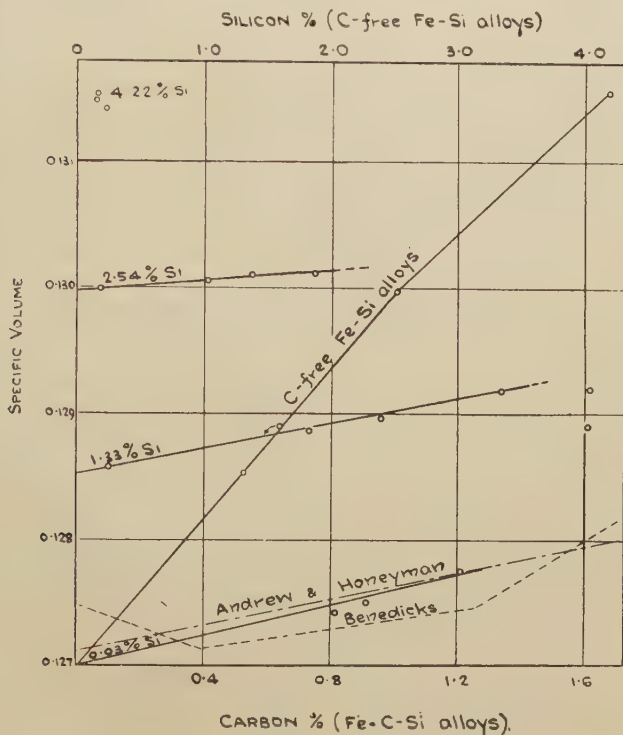


FIG. A.

iron which determined the heat flow in the ingot mould. That was, of course, perfectly true, but he was able to say that, following a discussion between the Chairman of the Heterogeneity Committee and himself, a meeting of a sub-committee of the British Cast Iron Research

Association had taken place recently in Sheffield, at which both ingot mould makers and ingot mould users were represented. As a consequence, it was hoped to formulate a scheme of research, with the help of ingot mould makers throughout the country, which would provide for the systematic determination of those constants.

In view of the fact that the ingot mould and the ingot separated shortly after pouring, a fact which was mentioned in the First Report, it seemed necessary in addition to determine by actual direct experiment the temperature gradient across the mould, and that could be done only in the steelworks.

Virtually no information had been published on ingot mould iron, but a little had been obtained by his Association on specific volumes and specific heats on pure bases, and the results would give some indication of what might be expected with true cast irons. Thus, Dr. M. L. Becker had obtained specific volumes for various iron-carbon-silicon alloys, with the results given in Fig. A. Some figures due to Andrew and Honeyman¹ and Benedicks² were added for comparison. Fig. A also showed the variation of specific volume with silicon for carbon-free alloys. Some work was in progress on cast irons of compositions not very widely different from those used for ingot moulds. Specific heats had been taken on a range of actual cast irons for bars of varying sizes, but no connection, so far, could be traced between specific heat and composition or specific heat and size of bar.

On thermal conductivities and coefficients of radiation of ingot mould irons practically nothing had been done, and the fact that cast iron was not isotropic and not homogeneous would create very great difficulties in getting reliable determinations. It seemed probable, however, that cast irons would not differ markedly in those properties from one composition to another; they did not do so in the case of specific heats.

Mr. W. SIMONS (Member of Council) thanked the Committee for the important work they had carried out; it would be of great assistance to all, in particular those who had encountered difficulties with special steels. It went to show that the policy of the Institute in setting up such committees had been of great value to the industry.

Dr. FRITZ WÜST (Düsseldorf) said his experience was that the work of committees was seldom good, but the present case was certainly an exception, and he wished to compliment the Committee on the excellent and most important work it had done. He was proud that on the Committee were some of his English friends, and in particular one of his old pupils.

¹ *Iron and Steel Institute: Carnegie Scholarship Memoirs*, 1924, vol. xiii. p. 253.

² "Recherches Physiques et Physico-Chimiques sur l'Acier au Carbone," Upsala, 1904.

Professor J. H. ANDREW (Glasgow) said that when that part of the Report for which he was responsible was written, the work was in a very incomplete state, but it was now hoped to have the complete set of freezing and melting points finished within a fortnight.

Dr. Rosenhain had suggested a much easier way of doing the work; if he had had facilities such as Dr. Rosenhain enjoyed he might have adopted his methods, but tungsten wire cost about 1s. 6d. a foot and platinum £3 or so—a very serious difference.

With regard to the results, very accurate determinations of the melting points and the freezing points had been obtained. The solidus was not difficult to find on the thermal curve to within 2° C., and it was found possible to heat a sample, melt it, cool it, and heat it up again and get the same solidus and freezing points time after time without any change. The steel did not alter at all in composition; starting with 0.13 per cent. of carbon, after determination it was found to be still 0.13 per cent., or with carbon 0.9 per cent., after determination it was 0.89 per cent., which was sufficiently near. The results agreed remarkably well with those obtained by Professor Carpenter and Mr. Keeling many years ago, if the correction—which was Professor Carpenter's own—of 37° C. were added to their determinations; with that correction the figures for pure carbon steels were coincident.

Mr. T. M. SERVICE (Glasgow) agreed with other speakers that the Report consisted chiefly of facts, which were difficult to controvert unless other facts could be put up against them. It was general practice in certain surveys to ask for definite information on the segregation in various parts of ingots, and particularly in actual manufacture it was quite a common practice to take the carbon, sulphur, and phosphorus at the top end of each ingot. Some of the ingots mentioned in the Report had been investigated for carbon, sulphur, and phosphorus, and the average agreed with what was given in the Report. For Air Board specifications it was often necessary to section the ingot on the centre line and take a sulphur print to show the degree of segregation in the ingots employed, and those also agreed with what was shown in the Report. He thought it might be taken, therefore, that the ingots dealt with in the Report did represent everyday practice.

Another point raised by Dr. Rosenhain was that the segregation shown in the sulphur prints of the ingot sections might diffuse during the heating and the after-working. There was a certain amount of evidence on that point. Many forgings had been sectioned and sulphur-printed, and the segregations revealed were similar in type and apparent amount to the prints in the Report. It was a difficult matter to get evidence free from criticism on that point, as, if a centre section after sulphur printing were reheated to a forging temperature, it scaled so badly that the surface had to be replaned and polished before taking another sulphur print, and consequently that new surface might be

anything up to $\frac{1}{2}$ in. distant from the first surface printed. His experience showed that no diffusion, or practically none, took place in a heating time up to 24 hrs. at 1200° C.

Mr. F. W. HARBORD, C.B.E. (Past-President), referring to the ingot cast in the electric furnace, asked whether the temperature was much higher than would have been the case had it been cast in an open-hearth furnace with the same size charge. Dr. Hatfield had said a 45° C. drop occurred between the first ingot and the fourth. It was often found, in basic open-hearth practice, that there was a variation in the analysis of the ingot cast first and that cast last, due largely to segregation, and that to some extent might be influenced by the temperature drop. Whether the temperature drop in an ordinary open-hearth steel cast of, say, 50 tons was more or less than 45° C. he could not say, but perhaps Dr. Hatfield could give some more information on that point.

The present was one of those cases which showed the enormous amount of good that could be obtained by the co-operation of the industry with men who had had practical experience and wide technical training to carry out the work under proper scientific control. He thought both the industry and the Iron and Steel Institute were to be congratulated on having got the Committee together and arranged for the very exhaustive experiments which had been carried out.

Professor H. C. H. CARPENTER, F.R.S. (Hon. Treasurer), said there was one point in connection with the Report to which he wished to refer, namely, finance. He wished the members to realise how costly the investigation had been. Professor Desch had mentioned how very much the academic members of the Committee appreciated the really splendid way in which the generosity of the works of this country had made the work possible. No figure had been mentioned, but the cost must be thought of in terms not of thousands, but of tens of thousands of pounds. He thought that ought to be stated publicly. Considering the difficulties through which the steel industry had passed during the last six years, this effort was most creditable to it.

The Council itself was doing its part, and he might mention that the Report as it stood would cost about £300 to publish; but he was very glad the Institute was spending money in that way. He did not believe it could be spent in a better way, and he thought it should be emphasised that the work was the first piece of investigational work of this kind for which the Institute as an Institute had made itself responsible.

Mr. E. A. ATKINS (Warrington), referring to the future work of the Committee, said he had two lines of investigation in his mind. He considered that some experimental work should be carried out on the kind of additions which should be made to the ladle, and their effect, not only on the amount of segregation but on the size of inclusions. He was quite convinced that it was possible to make additions to the

ladle which would affect the upward displacement of the inclusions, particularly if those inclusions could be made to coalesce. The other line of investigation, which was probably fanciful, would be a comparison of dead or static freezing with what he might call dynamic freezing. At present all freezing was static; the liquid was allowed to freeze naturally. If the mould were subjected to intense vibration while the steel was solidifying, would it have the effect of throwing down the chilled crystals, and would it affect the convection currents? If so, what would be the result on the mass of steel when it had completely solidified? Those were two lines of investigation which he suggested might be followed up with good effect.

The PRESIDENT said the subject was one in which he had been greatly interested ever since 1894. In that year he was in America, and his firm started an investigation on segregation. They had a particular iron which carried a lot of copper, from which they were making spring steels, and he had to find out whether the copper was going to segregate in the same way as the metalloids. He was very thankful to find that he had to confine his attention largely to carbon, phosphorus, and sulphur.

Dr. Rosenhain had asked whether the Committee would turn its attention to the investigation of ingots with liquid centres. Undoubtedly many large ingots at the present time were rolled with liquid centres, and he believed that their examination would be a very interesting and important division of the Committee's work.

The other type of ingot he would like the Committee to investigate was one of a pure kind of ingot iron containing not less than 99·60 per cent. of iron.

CORRESPONDENCE.

Professor C. BENEDICKS (Hon. Vice-President) (Stockholm) wrote :

1. The writer recognises the wisdom of the Committee in not attempting the production of a detailed theory of the phenomena involved in the freezing of an ingot, in view of the multiplicity of the processes occurring. Having lately, in collaboration with Mr. H. Löfquist, Met. Eng., devoted much time to the question of the distribution of slag inclusions, he was, however, struck by the fact that two distinct types of ingot freezing might be distinguished, which threw a new light on the subject. The Second Report contains such valuable material, supplementary to that presented in the First Report, and also supports these views, that the writer ventures to offer here a short theoretical survey of ingot freezing—in much the same way as the question will be treated in a monograph on slag inclusions to appear later.

2. *Thermal Centre*.—In any cooling body there will be a point, or a portion, characterised by a slower cooling than the mass outside; it

may be designated as the *thermal centre* of the cooling body. For reasons of symmetry, the thermal centre must be situated on the geometrical axis, say, of a prismatic body. In general, the thermal centre ought to coincide with the centre of gravity (a given body absorbing heat in proportion to its mass). The manner of the external heat loss of the body will, however, generally cause a difference in the situations of the thermal and gravitational centres.

3. *The Two Cases.*—The two cases now to be distinguished are simply these: the thermal centre of an ingot may be situated:

A. In the lower half of the central line,

B. In the upper half of the central line.

Case A corresponds to an ingot with the wider end downwards (ordinary cone, Fig. B), or to an ingot of uniform thickness—or even to one having the wider end upwards (reversed cone)—which is more intensely cooled at the top.

Case B corresponds to an ingot with the wide end upwards (reversed cone, Fig. C) or, in any case, to one which is prevented from cooling quickly at the top. This case, as will be seen, gives the freezing mechanism always aimed at for a piping, high-quality steel.

It is scarcely necessary to point out that the limit between the two types might sometimes be a rather variable one. Thus, an ingot might start freezing according to type *B*; later on, when even the ground under the ingot mould has been highly heated, and the cooling may be effected mainly by the circulation of the air—necessarily cooling the top much more than the bottom—then the freezing may continue according to type *A*.

4. *Molten State.*—The molten low-carbon steel, the freezing of which is to be considered, may be assumed to contain a fairly high amount of slag or non-metallic substances: (a) as a separate, more or less highly dispersed phase, having very low solubility even in the molten metal—say silicates; (b) as a separate phase, having, however, a certain solubility in the molten metal, but a very low solubility in the solid metal—say (Fe, Mn)S.

While in the mould, before any noticeable freezing takes place, a slow concentration of the dispersed slag phase towards the top takes place—essentially according to Stokes' formula. A Ludwig-Soret effect may occur, but may be disregarded here.

5. *Chill Layer.*—Now, the first stage of the freezing, in any case, will be the formation of a more or less thin *chill layer* 1 (Figs. B and C), due to the primarily low temperature of the mould.¹

¹ The formation of a chill layer is conveniently ascertained in the following (inverse) way: some paraffin-wax is melted, say, in a glass beaker. If a thick brass rod be introduced a white solid crust is formed, and continues to grow. On the contrary, on a very thin rod, the formation of a chill layer is difficult to observe, while on a rod of suitable medium thickness a thin chill layer is formed immediately; it may soon disappear, or remain constant, according to the temperature of the melt and the temperature and heat capacity of the solid.

This chill layer—as is well explained in the First Report—possesses a fine-grained structure, on account of the quick cooling. For the same reason it might be assumed to contain sensibly the same amount of slag as was originally present in the melt—the quick cooling opposing the expulsion of the slag. The chemical composition of this layer, on account of the quick cooling, will also be sensibly that of the melt.

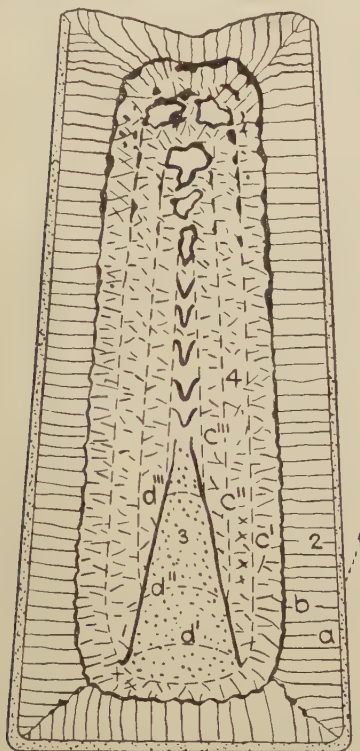


FIG. B.—Type A.

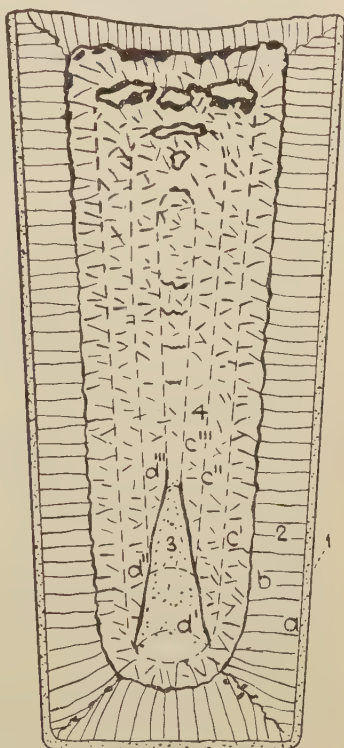


FIG. C.—Type B.

The chill layer, however, may wholly or partly disappear, such as in the case of very hot steel, or a very thin mould.

6. *Columnar Zone*.—As soon as the heat loss of the melt permits, crystals will start from the inner boundary *a* (Figs. B and C) of the chill layer, growing inwards. These crystals will necessarily be elongated, as they must grow in the (negative) direction of the temperature gradient.¹

¹ This simple fact seems to be far from being universally understood. In the discussion of the First Report, however, similar considerations were well set out by Mr. H. Brearley (*loc. cit.*, p. 156). It may be said that at any instant the columns formed point roughly towards the thermal centre of the ingot.

On the other hand, it is not quite obvious why they form such thick columnar crystals as those found in the *columnar zone 2*. In the discussion of the First Report the present writer pointed out this as being probably related to local convection currents¹—as is probably the case with the large basalt columns.

On the same occasion, he questioned whether the thickness of the columnar zone were not determined by the instant at which the wall of the mould was heated up to a nearly uniform temperature. Since then Mr. Gejrot² has shown, by pyrometric measurements, that the position of the inner boundary of the columnar zone is determined by the moment when the mould and ingot separate—an instant probably nearly related to the former one, and evidently inducing a slower cooling of the ingot.

The inward extension of the columnar zone 2 formed in this way may be represented by the lines *b* in the diagrams.

It may be pointed out that on the whole this *columnar boundary must coincide with a certain isothermal*, in the same way as the direction of the columns coincides with the direction of the temperature gradient (both being normal to the former ones).

Further, regarding this columnar boundary, a noticeable difference exists between case *A* and case *B*. As indicated diagrammatically in the figures, this difference consists in that in case *A* the columnar boundary will generally present an *inward slope* (towards the top), showing the appearance of a vault (or Λ -shape), while in case *B* the columnar boundary in the larger portion of the ingot will present an outward slope (towards the top), or have a funnel-like appearance (*V*-shape). This difference is highly important for the resulting slag distribution of the ingot, as will be shown. Similarly, in case *A* the direction of the columnar crystals (of the middle portion of the ingot) will have a downward trend, while in case *B* they will have an upward trend.³

Now, the columnar crystals, like all growing crystals, have the power of rejecting out of their lattice more or less completely all foreign bodies not giving a solid solution (*Selbstreinigungsvormögen der Kristalle*, according to O. Lehmann). On this account the growing columnar crystals will reject and push before them a certain layer of slag. This will contain the silicate and sulphide grains, assumed to pre-exist in the liquid, as well as the sulphide successively thrown out of solution on the solidification of the iron.

Now, it is obvious that *this expelled slag layer will be much more considerable in case A than in case B*. On account of the inward slope there is in case *A* very little probability of the slag particles leaving the columnar boundary; on the contrary, in case *B* the tendency of the slag particles to move upwards—due to their specific gravity being lower

¹ *Journal of the Iron and Steel Institute*, 1926, No. I. p. 169.

² *Jernkontorets Annaler, Tekniska Diskussionsmötet*, 1927, p. 121.

³ Thus, the upward trend of the columns mentioned on p. 108 of the First Report is only a special case.

than that of the molten iron—will enable part of the expelled slag particles to leave the columnar boundary and rise in the liquid. Besides this, the slag particles which are rising from the lower part of the liquid will easily be arrested on the columnar boundary in case *A*, while in case *B* they evidently may rise to the top.

On account of this, the ghost lines thus formed by the *slag* particles (marked by dark parts on the lines *b*) will

in case *A*: have an inward taper (towards the top, \wedge) and be rather bulky;

in case *B*: have an outward taper (towards the top, \vee) and be much less considerable.

During the solidification of the columnar zone, as is well known, the melt is enriched in carbon and phosphorus. This enrichment is more marked when the solidification is rapid.¹ On the contrary, a rapid solidification gives in itself *less* difference in the *slag* distribution between the columnar zone and the melt.

7. *Region of Granular Growth, including the Sedimentary Cone.*—The next stage in the freezing process will naturally be a new start of the crystal growth, setting in from the columnar boundary.

However, during the pause in the cooling, caused by the gap formed between the ingot and the mould, and also due to the slowing down of the cooling itself, a great number of crystallisation nuclei will have found time to form in the liquid—as is always the case in a liquid kept near its freezing point (Tammann). Hence, crystallisation might be supposed to set in almost anywhere in the liquid. There is, however, scarcely a single case known where this has been proved to occur. If, on the other hand, the liquid contains *solid* slag particles, it is highly probable that the crystal nuclei will cause iron crystals to start growing on them.

If, instead, the slag grains are *liquid*—say as silicate drops—it might seem much less probable that they should be able to induce crystal growth. It should be borne in mind, however, that the carbon concentration of the liquid—which has increased during the formation of the columnar zone—may be expected to be lower around such a slag drop. If this be the case, the iron immediately surrounding a slag drop must have a stronger freezing tendency than otherwise. Hence, it appears quite reasonable that in any case *slag particles, whether solid or fluid, may act as starting-points for crystallisation.*

Further, though no measurements are available, it seems probable that iron, like all normal metals, contracts when freezing.² Assuming

¹ Not the reverse, as was indicated in the First Report, p. 103. In order that a high cooling rate should result in a lower degree of heterogeneity, the rate of cooling must be much higher than that attainable in ingots—except possibly in the chill layer.

² It is true that the determinations on liquid iron made so far at the Metallografiska Institutet, Stockholm, do not allow for any large contraction on freezing; this certainly does not exclude a small contraction—which appears probable in itself.

this to be true, the crystals formed—including any original slag particles—must finally grow heavier than the liquid, which, besides, contains more carbon and other impurities. Consequently, as already explained in the First Report, and supported especially by Mr. Dickenson, it seems probable that small “equiaxed crystals of relative purity begin to form in the central portion of the ingot and fall towards the bottom.”

Admitting this to be true, the crystallisation belonging to this stage will be of a duplex character: (1) a more or less irregular or granular crystallisation, proceeding inwards from the inner boundary of the columnar zone; (2) a “snowing” down of small crystals, or, better, crystal groups, each one presumably carrying a slag particle.

Suppose, now, at a given instant, the crystallisation (1) to have reached an isothermal c' . The crystals formed in this layer (bc') will presumably expel a good deal of slag, in the same way as those of the columnar layer, though less completely. Hence, ghost lines are to be expected likewise on the surface c' . At the same time, the free iron crystals generated in the liquid—according to the assumption made—will form a “drift” d' at the bottom. At a later instant, boundary curves c'' and d'' , respectively, occur, and so on. In this way—in full harmony with the First Report—two regions are to be distinguished in the interior of the ingot: in the lower part, a cone 3, formed by the falling crystals, for which the expression *sedimentary cone* is proposed here; the remaining part of the interior situated above this may be designated as the *region of granular growth* 4, being formed by a more or less irregular crystal growth towards the axis of the ingot.

This explanation of the inner structure of the ingot is well supported by the following facts:

- (1) The inner cone 3 (at least the lower portion) consists of a remarkably pure iron, otherwise hard to explain.
- (2) At the same time it generally contains a rather high amount of silicate slag (Dickenson), otherwise difficult to explain.
- (3) The existence of the conical region in itself would be very difficult to explain in any other way.

Comparing now case *A* and case *B*, it is obvious that the new ghost lines, generated along curves like c' , c'' , will—in the same way as those on *b*—be *much more prominent in case A than in case B*. Further, as is easily seen, the sedimentary cone 3 will be much more developed in case *A* than in *B*.

8. *Residual Contraction, causing V-Segregation.*—When, finally, the freezing has proceeded so far as to reach a boundary c''' , only a “comparatively narrow central channel of remaining liquid steel” will exist. As explained in the First Report (p. 112), the final solidification of this portion will cause the appearance of the “V-shaped central zones,” as in the last solidifying portions some irregular segregation seems inevitable.

Now, these V-shaped formations will evidently be *much more pronounced in case A than in case B* (on account of the central portion limited by c''' being much wider in the lower part in *A* than in *B*).

9. *Shrinkage Cavities*.—Still more important is the difference between cases *A* and *B* as regards the formation of shrinkage cavities—mainly due to the melt having primarily a high temperature, above the melting point. As is easily understood—though only roughly shown in the figures—the shrinkage cavities will be *much more pronounced in case A than in B*, both in regard to their size as well as to their extension downwards.

This expresses in a clear way the physical reason for the endeavour made, more or less consciously, towards the production of ingots of the type *B*, at least in the case of quality steel. Exception is made only in the case of the production of ingots for the cheaper plates and tubes (cf. Second Report, p. 404).

10. *Influence of Gas Evolution*.—The evolution of gases, in the examples given in the Second Report, causes but very slight modifications. Most prominent are the elongated gas cavities formed in the columnar zone; the V-segregations are rendered more diffuse (p. 528).

Certain experiments made by F. Badenheuer¹ at Bofors, Sweden, and at the Krupp Works in Essen, in conjunction with C. Gejrot² are of interest here. It was found that the evolution of gas causes the sedimentary cone to extend very considerably towards the top, and a much more uniform temperature is obtained in the inner regions.

11. *Conclusion*.—This analysis of course does not pretend to describe correctly all the details of ingot freezing, but the writer hopes that it presents the fundamental factors in a more precise way than former accounts.

It is of some interest to examine the examples given in the Reports from the point of view of the two freezing types as set out here. It is found thereby that by far the majority of examples belong to type *A*.³ Thus, in the Second Report, Figs. 28, *f* and *g*, and Fig. 33, *f*, appear rather typical of type *A*.

In the First Report there is scarcely any representative of type *B*; in the Second Report, Fig. 20, *f*, and Figs. 27, *f* and *g*, seem to illustrate this case. The best example is that given by Dickenson⁴ in his

¹ Doktor-Ingenieur Dissertation, Aachen, 1927.

² *Loc. cit.* p. 150.

³ It may be appropriate to point out again that type *A* and type *B* by no means are characterised by having the wide end down and the wide end up respectively. As a matter of fact, the figures (B and C) were drawn in this way only in order to make things more visual; as clearly stated above (in 3), type *A* may also have the wide end up, or be of uniform thickness, and *vice versa*. The definition of the two types actually only implies that the thermal centre is a low one (type *A*) or a high one (type *B*). The shape of the ingot mould is but one of the several factors determining the situation of the thermal centre; bottom or top pouring, cooling conditions, such as wall thickness of the mould, and so forth, are other influencing factors.

⁴ *Journal of the Iron and Steel Institute*, 1926, No. I. p. 177.

Fig. 7 (Ni-Cr steel); in this case the upward trend of the columns is conspicuous.

To judge from this examination, it seems that in practice the top of the ingot might still be cooled too much, and that a good deal might be gained by heating the top, say, by means of the blast described by Sir Robert Hadfield in 1912—or, perhaps, by means of a transferable induction coil.

Mr. H. D. HIBBARD (Plainfield, U.S.A.) wrote: This Second Report is even more interesting than the First, and gives one lively and pleasant anticipations of more to come. The section on moulds is particularly valuable and timely, but one would like to see the composition of some of the smaller moulds as well as of the larger. The great requirement for mould iron is perhaps that it shall be soft, with much graphite, which is favoured by slow freezing and high silicon. In such a thick casting as a heavy mould the slow rate at which it cools is sufficient, so that high silicon is not required. In a small, relatively thin, mould the silicon should be perhaps around 1.50 per cent. instead of 1 per cent. as in the large mould, the analysis of which is given on p. 412. The long life of that mould was no doubt due in part to its exceptionally low sulphur and phosphorus.

One wishes that some good ingots of effervescing or rimming steel had been included in the research. Examples 24, 25, 26, and 27 were all too thin-skinned, the metal having presumably lacked the proper boil in the furnace, so that it contained too much skinhole gas. This gas separated from the metal too soon in the mould, forming skinholes too near the surface. Example 24 was manifestly cast too hot. Ordinary good rimming steel ingots have solid skins at least 1 in. thick, and more often 2 in., or even more.

Though on p. 478 the statement appears that no additions of silicon or aluminium are made to such steel, yet both these elements have their uses in making rimming steel. Aluminium is added in the ladle or mould to counteract an undue tendency to settle when the evolution of gases in the mould is too copious. The examples illustrated in the Report did not need any, however.

The effect noted, also on p. 478, of the addition of sulphur tending to kill the steel is of especial interest. It shows still another part of the field, covering the composition, behaviour, and control of the gases of molten steel, to be explored.

The Report also confirms the anomaly that the more steel moves or churns in the mould the more it segregates, just the opposite of what one would expect. If the general statements made regarding steel manufacture were exemplified by concrete instances, the Report would have still greater value for the man in the shop.

Dr. T. SWINDEN (Sheffield) wrote: Everyone will agree that the Report represents a very large amount of painstaking work on the

part of the Committee, and generous support on a large scale by the industry.

The section on ingot moulds is a valuable collection of data, and provides a basis for a standardisation of moulds, which is very desirable.

It is very gratifying that the Committee has turned its attention to the semi-killed and rimming types of steel. There has been a feeling in certain quarters that such steel should not be recognised as orthodox or representing good steel-making practice. On the other hand, it has been well recognised in the trade that the dead solid piping steels represent a comparatively small, though very important, proportion of the total production of steel ingots in this country. If only from the fact that practically the whole of the Continental steel, which is playing such a serious part in the economic position of this country, is of the rimming steel type, it would warrant the serious attention of the Committee.

One point on which the Committee will at once agree is that the ingots examined should be definitely representative of their type.

Examples 24 and 26 are presumably steel of the rimming type, but I seriously question whether they do justice to it. If the subject is examined from every point of view, including the influence of the degree of oxidation, temperature, casting speed, and method of casting, it will be found that the occurrence of serious blowholes in the lower half of the ingot can be controlled. I would suggest that Example 24 does not represent the best type of tube steel ingot. Incidentally, this does bring home the necessity of longitudinal sectioning, or at least cross-sectioning both top and bottom, rather than relying on top sectioning to indicate the degree of unsoundness present.

Examples 27 and 25 are described as being examples in descending order of gas evolution. Judging by the illustrations, however, Example 27 appears to have a deeper surface chill and to have been more heavily oxidised than Example 25. One feature that should be mentioned is that the paragraph in the middle of p. 478 might lead to a misconception of what happens in gradually reducing the degree of oxidation or degree of gas evolution from the rimming steel, as illustrated in Example 24, and the "balanced" steel having no definite pure chill zone but a certain proportion of blowholes. It is well known that between these two types the steel may be in such a condition as to be extremely wild, and to be of such a nature as to rise over the top of the ingot mould. It is further well known that if the degree of oxidation or gas content is much higher than would be the case in Example 24, the steel sinks in the mould, and may produce an ingot of only half the original length to which the mould was filled.

Example 29 is interesting as illustrating the well-known fact that sulphur exerts a killing effect on the steel and produces a dead solid ingot with a material that otherwise would not be solid.

Several speakers at the meeting referred to the future programme

of the Committee, and I take it that the Committee welcomes such suggestions. In the first place, all the ingots examined have presumably been allowed to cool normally in the moulds. It is well known that it is desirable (and a very large proportion of steel is actually so handled) to forge or roll the steel without allowing the ingot to go completely cold. There is no doubt that this has a very important bearing on the heterogeneity. It would appear to be of considerable practical importance that certain representative ingots should be reheated, as would occur in practice, to the forging or rolling temperature without having been allowed to cool down, and should then be withdrawn, cooled, and examined. A further check on this of a still more practical character is to examine the rolled material at points corresponding to various positions in the original ingot.

This Report was also presented at the adjourned meeting held in Sheffield on May 10, 1928. The following remarks are extracted from the discussion which took place :

Mr. A. J. CAPRON (Sheffield) asked whether the Committee had made any examination of the effects of the fluid compression of steel ingots. As was well known, a good deal had been done in the past in the compression of large ingots as used for forging purposes, both on the Harmet and the Robinson and Rodgers systems. The latter system had also been in use for a long time at Messrs. Jessop's works on crucible steel ingots. Both systems had proved effective, not only in eliminating piping, but in greatly reducing segregation.

Professor C. H. DESCH (Member of Council) remarked that he considered it probable that if ingots were examined after a period in the soaking pit as well as after being allowed to go cold without soaking, a difference in the distribution of the carbon would be found in low-carbon steels; he thought it unlikely, however, that any serious difference would be found in nickel-chrome or other alloy steel ingots, on account of the extreme slowness of diffusion in the presence of alloying metals.

Mr. A. SENIOR, C.B.E. (Sheffield), said that, in case the Committee was not aware of it, he would mention that about 30 years ago a Swedish engineer tried to make ingots sound by subjecting them to centrifugal motion directly after the metal was poured into the ingot mould. He succeeded in making very sound ingots by that process; it was discovered, however, that analyses taken from the outside of the ingot showed scarcely any trace of either phosphorus or sulphur, while, on breaking the ingot in two, it was found that those two elements in particular had segregated into the centre of the ingot to such an extent that they showed liquation. When it was borne in mind that the average analysis of that material was about 0.028 to 0.03 per cent. of phosphorus, and sulphur 0.01 per cent., the resultant steel was not

of much use in commercial practice. The ingots had to be melted up for scrap, and the process was discontinued for making ingots, though it was used later for casting hollows.

Dr. HATFIELD, in a verbal reply, expressed the Committee's thanks for the many kind things that had been said during the discussion.

The Committee appreciated Dr. Rosenhain's comments. With regard to the preparation of a small report, in the nature of a summary, that might be desirable, but it was difficult to carry out. For people who were interested seriously in steel ingots it was surely not too much to ask them to read the Report. The interest taken in ingots by the user was to-day very considerable. In fact, he must confess—and he thought many members of the Committee would share the view—that he sometimes felt that the user of the ingot knew more about the ingot than the manufacturer. At any rate, very keen interest was taken in the efforts of the Committee, and they had upon occasions received help and assistance with regard to methods of production from people who, strictly speaking, were really external observers.

That brought him to a very interesting point raised by Mr. Atkins, namely, the nature of the future work of the Committee. The Committee considered they had now given an adequate picture of the state of the art, which rendered it possible for those interested to draw their deductions, but it might be asked what they were going to do to improve matters. He could say on behalf of the Committee that it was their intention to put in hand constructive experiments and to test various avenues of possible improvement, but he wished to say, on behalf of the Committee and of that portion of the steel trade that had contributed to the work, that it was not only for the Committee to do that work. The data were now available to the industry of both this and other countries, and sufficient information had been given for the technical world at large to draw its own deductions and to make its own experiments. He had reason to believe that, apart altogether from the work of the Committee, the steel industry was drawing its deductions and utilising the information that had been given for the improvement of the technique of the industry.

He thought it was fair for the Committee to ask that when work of that kind was done those who did it should contribute the data they obtained to the Committee. He did not suggest that that should necessarily be done, but it would be a generous act on the part of any steel-makers who profited by the Committee's investigations in the manner he was discussing if, when they tried some of the avenues opened up and found success, they would contribute the data, which would thus be available for the industry as a whole. In other words, an even broader collaboration than was found practicable in the initial stages would be welcome.

He would like to say to Dr. Rosenhain that whilst, for instance, a 12-ton ingot and a 25-ton ingot might be given in the Report as

representative of a class, Dr. Rosenhain could have his personal assurance, which the Committee would endorse, that never were particulars of an ingot given without other ingots having been studied. It might be of interest to say that of ingots weighing as much as 25 tons as many as half a dozen had been cut open, but the results of one only were given in the Report. He was sure the Hon. Treasurer of the Institute would object strongly if the Institute were asked to provide for the publication of the mass of data which was readily available in compliance with Dr. Rosenhain's suggestion. The Committee had to content itself with giving examples.

With regard to how far diffusion occurred on reheating, in the introduction to the First Report (pp. 41-42) it was stated that after due consideration the Committee were of opinion sufficient evidence existed, based on the examination of blooms, to clearly indicate that the time-temperature effect resulting from soaking really did not lead to any substantial diffusion of the elements.

Concerning the effect of the Harnet process, he would point out, on behalf of the Committee, that during the discussion of the First Report the Committee expressed the wish to examine ingots produced under fluid compression, but apparently there were no ingots available at the time. If any steelworks, either at home or abroad, did possess such ingots of which sufficient information was available concerning their production, it would be advantageous for the Committee to have the opportunity of putting on record the valuable information for which Dr. Rosenhain had asked.

He could assure Dr. Rosenhain that he was wrong when he said that theorising must be a painful matter for the Committee; some of their most delightful afternoons had been spent in trying to reach unanimity with regard to their views as to the mechanism of freezing.

Dr. McCance had made an excellent contribution to the discussion which the Committee appreciated. With regard to the effect of tapering and what was the best taper, he would refer Dr. McCance to the different designs of moulds given in the present Report; some were practically without taper and some had substantial taper, and if Dr. McCance would study the sections he would find some of the information for which he asked. If Dr. McCance had any data on the effect of varying tapers on ingots and would hand it to the Committee, they would very much appreciate it.

The thanks of the Committee were due to Mr. Simons and Dr. Wüst for their very kind remarks.

With regard to Mr. Harbord's question concerning temperature, he was very glad that point had been raised, because in introducing the Report he did not sufficiently emphasise that section of it which dealt with temperature. He would now like to say, on behalf of the Committee, that it was felt that the science of taking temperatures at high temperatures was not very advanced, and he thought those

physicists who were working in that field should be persuaded, if necessary by financial assistance, to give particular attention to the subject. He might say, however, that there was a very reasonably satisfactory instrument, which, if intelligently used with proper allowances, did enable one to take fairly good comparative records of the temperature of the steel; that was the Cambridge optical pyrometer. That instrument was generally used in determining the liquid temperatures stated in the Report. With regard to Mr. Harbord's specific question, the 45° C. drop in temperature was bigger in the case of the electric furnace than in the case of the open-hearth; it was found that in the small casts the heat was lost much more readily, and the same drop per ton was not found in the large casts.

The Committee very much appreciated Professor Carpenter's comments, and he was sure Professor Carpenter would forgive the Committee for their utter helplessness to effect economies with regard to cost of publication.

The Committee very much appreciated the comments the President had made. It had been the wish of the Committee to examine ingot iron, and they had endeavoured to obtain such ingots. Unfortunately the firms directly represented on the Committee were not producers of that material, and they would welcome an offer from some firm producing the material, which would enable them to carry out an adequate examination such as had been made of the other ingots. If the President could assist them in that direction his help would be very much appreciated.

In further reply the COMMITTEE wrote that they much appreciated the various contributions which had been made during the discussion. Their acknowledgments were due particularly to Dr. Rosenhain for his opening remarks. Regarding his subsequent observations, the whole scheme of the research should be considered when any generalisation as to its nature was being made, and if, by the "natural history" method, he (Dr. Rosenhain) wished to convey that the work hitherto had largely consisted of exact observation, they were prepared, so far, to agree with him. They had, however, very thoroughly discussed and endeavoured to define the effect of many variables, introduced both by the design of the mould and the ingot, and also by the composition and by the metallurgical processes. The Committee thought that a careful consideration of the whole of the work so far published, coupled with the institution of important co-ordinated researches at Sheffield and Glasgow, would make it clear that a considerable research of a thoroughly scientific character was being carried through. The merit of the work must be judged in years to come by the extent to which its object of indicating the means of improving the technique of ingot production was ultimately achieved.

As regards the possibility of lessening the degree of heterogeneity by time-temperature effects in the soaking pit, they were able to inform

him that they had a mass of data which indicated that the differences in composition persisted after such procedure.

They welcomed Dr. McCance's contribution and his acceptance of the data presented. In reference to his remarks on ingots Nos. 17 and 18, it should be pointed out that those related to the degree of segregation shown in Figs. 20 and 21. With regard to ingots Nos. 19 and 20, it had evidently escaped Dr. McCance's notice that No. 19 was cast at a much higher temperature than No. 20. They were in agreement with what he said concerning the value of being able to compare different ingots from the same charge.

They were pleased to have given an impetus to Mr. Pearce's desire to explore fully the physical constants of cast irons as used in ingot moulds, and they hoped that the necessary data over the range of temperature in which they were interested would shortly be forthcoming.

To Mr. Harbord they desired to express their thanks for the interest he had taken in the work.

They were pleased to be able to state that work upon the nature of the non-metallic inclusions, as suggested by Mr. Atkins, was already in hand, but he would realise that the subject was a very large one. Various experiments had been made in the past for the purpose of studying the effect of vibration, but the results were not encouraging. The Committee hoped to follow up the President's suggestion of examining an ingot of pure ingot iron in the near future.

Turning to Dr. Benedicks' constructive contribution, which was, indeed, a paper in itself, they felt tempted to be drawn into a reply on several points. Dr. Benedicks would, however, appreciate that that would mean the breaking of their considered resolution not to attempt an explanation of the mechanism of the freezing of steel ingots at the present time. In the meantime, they were content that he should have provided his valuable contribution.

With regard to the remarks made by Dr. Swinden, the Committee agreed that the semi-killed and rimming types of steel formed a very important class, the study of which called for serious attention. They also agreed that any ingots put forward should be representative of their type. Dr. Swinden thought Examples 24 and 26 did not do justice to steel of the rimming type, which might be true, but as both those ingots were selected from a 60-ton heat, the bulk of which had been used for tubes and plates which turned perfectly satisfactorily, they thought that was sufficient to justify the inclusion of those examples in the Report as being examples of material which was commercially used.

The whole of the ingots shown in that section represented types which were widely used. They did not represent the best nor yet the worst ingots for making into plates, tubes, &c., but as one of the fields under investigation by the Committee was the effect of casting temperature and degree of oxidation, those ingots were put forward as illustrations of those effects. The presence of serious blowholes in the bottom

end of Example 24 was pointed out—in the Report—as being an abnormal and accidental occurrence in that particular ingot. With regard to Examples 27 and 25, if Dr. Swinden would again refer to the Report he would see that Example 27 was described as being more oxidised than 25, so that in that particular they were in agreement.

The Committee wished to thank Mr. Hibbard for his contribution. They agreed that the ingots were thin-skinned, but yet would point out that large numbers of satisfactory plates were regularly made from such ingots. It might be of interest to Mr. Hibbard to know, however, that Example No. 27 had in fact a solid skin $1\frac{1}{2}$ in. thick, although from the small-scale reproduction of the sulphur print that was perhaps not discernible. The Committee agreed that, for tubes fabricated by certain processes, it was essential that solid skins of the thickness quoted by Mr. Hibbard should be produced, and also that silicon and aluminium had their uses in making rimming steel; in fact, they would go further and say that the presence or absence of those two elements was of most vital import.

Once again the Committee would point out that in this particular section of the Report the ingots shown were “types of ingots which are used,” rather than representative types of good, bad, or indifferent practice.

Mr. Capron and Dr. Rosenhain had mentioned “fluid compressed” ingots, and they hoped to be able to report upon such ingots in a future paper.

HEAT-RESISTING STEELS.

PART II.—MECHANICAL PROPERTIES.¹

BY DR. W. H. HATFIELD (SHEFFIELD).

INTRODUCTION.

THE author presented to the Institute last year Part I. of a report containing the results ² of investigations carried out in the Brown-Firth Research Laboratories, with the object of determining the varying degree of resistance to attack by various corroding gases at high temperatures exhibited by steels of diverse composition in the chromium, silicon-chromium, chromium-nickel, chromium-nickel-silicon, and chromium-nickel-tungsten series. In the present paper it is proposed to deal with the other equally important but different characteristic—namely, the mechanical strength of steels at a high temperature, as affected by the introduction of the special elements. Although the whole series of alloy steels mentioned above which have been shown to offer marked resistance to chemical attack differ greatly in the degree of strength retained at high temperatures, it is satisfactory to note that some of them retain high strengths, as well as a high degree of resistance to chemical attack, thus fulfilling the dual requirements of the so-called heat-resisting steels.

THE INVESTIGATIONS.

Only those investigators peculiarly interested in this particular field can appreciate fully the difficulty of presenting comparative data concerning the strength of steels at high temperatures. The efforts of numerous investigators, both at home and abroad, have greatly extended the knowledge concerning the effect of increased temperature upon steel, but, at the same time, have served to indicate the complexity of the problem. Since the author has arbitrarily selected, as the means of providing

¹ Received February 20, 1928.

² *Journal of the Iron and Steel Institute*, 1927, No. I. pp. 483-508.

comparative data, tensile tests at 800° C., a few words in justification of this procedure are necessary.

The actual conditions of test were as follows :—The test-pieces were 0.357 in. diameter, with a parallel length of $1\frac{1}{4}$ in. The specimen was heated *in situ* in an electric resistance furnace. The time taken to attain the temperature was three-quarters of an hour to one hour, and then the selected temperature of 800° C. was maintained for half an hour before the test-piece was pulled. The speed of pulling was in all cases at the rate of a quarter of an inch elongation per minute.

It is well appreciated that the results derived from a tensile test at high temperatures should be interpreted in a different manner from those obtained from such tests at ordinary temperatures ; but when allowance is made in accordance with existing knowledge, such values sufficiently afford a means of comparison. In considering a tensile test, one should refer the figures obtained back to the creep limit and fatigue value of the material. It is of great interest to do this, particularly as regards the limit of proportionality and the yield point. The latter two values can only be stated in terms of the refinement of the measurement obtaining during the test.

Since the introduction of the word “creep” to denote a phenomenon observed, in the first place, during the mechanical investigation of steel at high temperatures, there has been a definite feeling of insecurity with many concerning the behaviour of steel under such conditions. If, therefore, a definite law could be established which removed the present uncertainty concerning the response of steel under temperatures above the normal, much would have been achieved.

It has recently been stated ¹ that “the theory of plastic flow suggests that above a certain temperature—possibly even at ordinary temperatures—all metals flow under load if given sufficient time.” Surely plastic flow is not to be considered in such cases where materials are stressed within the range of stress within which they behave as practically elastic materials at a given temperature. Such a statement, however, follows Dickenson’s suggestion that “there seems to be no reason why a cold test-piece of, say, 0.30 per cent. carbon steel should not, in time,

¹ *Metallurgist*, 1928, Jan., p. 9.

be pulled in two by a load of $8\frac{1}{2}$ tons per sq. in.,” and that, given time, rupture would occur at normal temperatures with very much smaller values of stress. Dickenson’s deduction is held by the author not only to be mistaken, but to lead to an unnecessary confusion, in the minds of designers, which is really unwarranted by the experimental facts. The interesting experiments of Rosenhain and Hanson,¹ in which mild steel was stressed for five years and three months at 300° C. at loads ranging from one-third to two-thirds of the normal breaking stress, gave *no* support to such a view.

Space does not permit of the publication of the complete bibliography prepared by the author, nor of full discussion of the numerous results of previous researches. It is, however, established that if a tensile test-piece of steel is stressed, even at the ordinary temperatures, *above the elastic range*, yielding takes place with time. If the stress imposed is anywhere between the elastic range and the maximum load which the specimen will bear, initial extension is rapid; the completion of the extension inducible by the stress imposed takes a longer time, as would be expected. A mild steel test-piece stressed 6 tons above its yield point at 15° C. did not attain stability in dimensions until 22 hours had elapsed. The final completion of the plastic deformation over a period of time constitutes “creep.” If, however, the test-piece is stressed within the elastic range, elastic deformation is produced according to the well-known law, and when the stress is removed the test-piece assumes practically its original dimensions; always with the reservations necessarily due to very minor initial effects resulting from heterogeneity of structure. The author’s experience would lead him to state that such is indeed the type of deformation not only at normal, but at progressively increasing temperatures. Thus it is only necessary to determine a satisfactory method of measuring the intrinsic elastic range, and the whole matter becomes simple. Such a method has not been developed, nor are the fundamentals as yet the subject of complete agreement.

Before leaving the subject of creep, reference should again be made to the experimental results of Dickenson, which proved in a very practical manner that, particularly at high temperatures,

¹ *Journal of the Iron and Steel Institute*, 1927, No. II. pp. 117–122.

test-pieces would bear only a definitely lower stress if the load were gradually applied—indeed, that lower stresses, though materially above the elastic range, if maintained for a sufficiently long time, would break the materials with which he experimented. The disparity between the stress at which the steel will break, with time, as compared with the normal conditions of tensile testing, increases with temperature. The same phenomenon of creep comes into play, but the elevation of the temperature accentuates the time effect which is defined in the word “creep.” This time effect is observable under careful experiment at ordinary temperatures, as has been stated, and it becomes of increasingly serious moment as the temperature attains high values, and the effect differs with different steels.

The modified behaviour of mild carbon steel with increasing temperature has been well studied, and it is known that there is a definite increase in the maximum stress when passing through the range of temperature of 200° to 300° C., but that at progressively still higher temperatures this value rapidly and consistently falls. The interesting feature is that since the yield falls from an original value of, say, 18 tons per sq. in. gradually from normal temperatures upwards (see Table A, 0.14 per cent. carbon steel), it is fair to deduce that the actual elastic range is progressively lowered at the same time, and probably more rapidly. If one studies the properties of this steel at 400° C., *i.e.* in the upper range of steam temperatures, it will be found that the maximum stress is very little below the value obtained at normal temperatures, but the yield has fallen 5 to 6 tons per sq. in. If at that temperature a load in excess of 14 tons per sq. in. is imposed over a sufficiently long time, it may be, as is at present suggested, that such stresses will break the specimen. This would, indeed, represent a very serious modification in properties as far as the designer is concerned. At 450° C. it has been suggested that 9.5 tons per sq. in. will cause “creep” until rupture takes place, whilst at 530° C. this value has been taken to be as low as 4 tons per sq. in. It is of interest to state that some of the hardened and tempered alloy steels enable at least 14 tons per sq. in. to be attained at 500° C. before continuous creep occurs. Nevertheless, within the range of “black heat,” the characteristics of the materials

would appear to be modified. When, therefore, one is considering the behaviour of steels at a red heat, it will be seen that, to say the least, aspirations towards obtaining really high elastic ranges at such temperatures do not offer much promise of fulfilment. Practice has taught the designer not to expect high stresses to be withstood over long periods under such conditions. For instance, mild carbon steels at 800° C. break under the ordinary tensile test at 3 to 4 tons maximum stress. If we examine one of the best heat-resisting steels available, we shall find that it will break at as high a value as 20 tons per sq. in. at least under the ordinary tensile test at that temperature, but its elastic range is low, and although its continuous creep value is probably in excess of 24 tons at 400° C., it is doubtful whether any stress in excess of 2 or 3 tons per sq. in. can be imposed over a long period at 800° C. without resulting in appreciable "creep." Such material, however, is applicable very successfully in those cases where the service at red heat essentially desired is permanence of shape, including section, so long as the imposed stresses are not of serious magnitude.

A complete study of the mechanical properties of any one steel over a wide range of temperature represents a large task, and, therefore, some arbitrary selection of test conditions based upon service conditions must be made if comparative values for a large number of steels are to be obtained. Since one particular temperature has been selected for the comparison of special alloy steels, the author considers it would be of value to show the bearing of this same temperature on some of the steels most widely known, and this is done in Tables A, B, and C. (The yield point corresponds, where stated, to 0.5 per cent. extension additional to the proportional extension.)

In Table A will be found the results of tensile tests at every 100° C. up to 1000° C. on carbon steels containing 0.14 per cent., 0.30 per cent., and 0.42 per cent. respectively.

Table B gives similar data for the hardened and tempered high tensile alloy steels.

Table C illustrates the values obtained from chromium, silicon-chromium, and chromium-nickel-tungsten steels.

In Table D will be found the analyses and condition of the steels dealt with in Tables A, B, and C.

TABLE A.—Tensile Tests on Carbon Steels at Elevated Temperatures.

Temperature.		0.14% Carbon Steel.					0.30% Carbon Steel.					0.42% Carbon Steel.				
		Limit of Proportionality.	Yield Point.	Maximum Stress.	Blongation.	Reduction of Area.	Limit of Proportionality.	Yield Point.	Maximum Stress.	Blongation.	Reduction of Area.	Limit of Proportionality.	Yield Point.	Maximum Stress.	Blongation.	Reduction of Area.
° C.	° F.															
15	59	17.8	17.9	27.2	38.0	61.0	21.6	22.2	36.6	26.6	50.3	25.0	26.6	41.0	22.4	47.0
100	212	15.8	17.7	28.1	34.5	60.0	18.6	18.75	33.7	23.2	54.7	20.5	23.2	40.08	23.2	49.0
200	392	14.9	17.3	30.0	27.0	58.0	16.4	20.7	40.7	22.4	46.8	20.0	25.0	43.68	17.6	42.0
300	572	13.1	15.5	32.5	23.2	55.8	14.3	19.4	43.55	18.7	35.5	20.8	25.87	49.67	13.6	23.4
400	752	7.8	12.9	25.2	37.6	68.5	10.1	19.4	40.7	28.0	50.6	15.5	25.2	42.0	28.8	58.0
500	932	...	...	20.0	38.0	73.0	...	15.0	28.6	30.4	65.8	10.0	20.7	33.5	25.1	58.2
600	1112	...	...	12.5	48.0	86.0	...	...	15.5	51.0	80.0	...	...	21.0	32.0	74.6
700	1292	...	...	6.8	56.0	93.0	...	...	8.07	48.8	86.0	...	...	10.1	44.8	48.0
800	1472	...	...	4.0	65.0	96.0	...	...	5.47	60.7	96.0	...	...	5.95	66.4	96.0
900	1652	...	...	2.0	75.0	98.0	...	...	3.75	68.0	97.0	...	...	4.17	56.7	90.0
1000	1832	...	...	...	...	...	...	...	2.65	78.0	99.0	...	...	2.42	80.0	99.0

TABLE B.—Tensile Tests on Hardened and Tempered High-Tensile Alloy Steels at Elevated Temperatures.

Temperature.		Heat-Treated 3% Ni Steel.						Heat-Treated Or-Va Steel.						Heat-Treated Ni-Cr Steel.					
° C.	° F.	Limit of Proportionality.	Yield Point.	Maximum Stress.	Elongation.	Reduction of Area.		Limit of Proportionality.	Yield Point.	Maximum Stress.	Elongation.	Reduction of Area.		Limit of Proportionality.	Yield Point.	Maximum Stress.	Elongation.	Reduction of Area.	
15	59	29.3	32.2	50.7	23.3	59.2		53.53	55.55	61.0	21.6	61.5		46.5	48.8	57.8	22.6	63.6	
100	212	28.0	34.4	48.5	25.0	56.4		53.9	57.5	62.6	20.0	63.0		34.4	47.5	56.4	23.2	67.7	
200	392	26.3	34.0	48.4	25.4	56.0		49.5	53.12	59.6	15.6	61.5		32.6	45.6	54.85	20.0	64.6	
300	572	25.2	33.6	47.7	21.0	57.0		43.5	49.2	55.6	20.0	59.0		37.0	48.5	55.28	20.0	50.2	
400	752	22.7	33.3	46.95	21.6	50.4		36.1	46.6	56.3	15.6	61.5		30.4	46.89	55.41	17.6	44.0	
500	932	...	22.4	29.1	28.0	79.4		15.5	27.0	32.6	26.4	74.4		22.0	38.97	44.91	21.6	66.5	
600	1112	...	11.75	18.67	40.0	89.8		...	...	24.8	30.4	87.0		...	...	23.62	32.0	88.0	
700	1292	...	...	11.5	48.0	96.0		...	...	11.6	52.0	92.0		...	...	12.31	42.4	90.0	
800	1472	...	...	6.53	71.2	93.0		...	...	6.7	68.0	95.0		...	...	5.6	74.3	92.0	
900	1652	...	...	4.025	56.0	83.0		...	...	4.7	81.5	96.0		...	...	4.53	52.0	84.6	
1000	1832	...	...	2.45	72.6	99.0		...	...	3.1	73.5	97.0		...	...	2.97	82.5	99.0	

TABLE C.—Tensile Tests on a Heat-Treated Cr Steel and Si-Cr and Ni-Cr-W Steels at Elevated Temperatures.

Temperature.		Heat-Treated 14% Cr Steel.						Si-Cr Steel.						Ni-Cr-W Steel.					
		Limit of Proportionality.	Yield Point.	Maximum Stress.	Elongation.	Reduction of Area.	%	Limit of Proportionality.	Yield Point.	Maximum Stress.	Elongation.	Reduction of Area.	%	Limit of Proportionality.	Yield Point.	Maximum Stress.	Elongation.	Reduction of Area.	%
° C.	° F.	28.6	35.7	48.5	28.0	62.5		48.5	59.0	68.0	20.0	49.0	23.2	36.0	63.0	23.5	24.0		
15	59							...	58.5	68.5	21.6	50.0	...	37.5	53.5	24.8	33.2		
100	212	28.0	35.8	45.9	24.8	65.4		...	50.2	63.0	21.6	52.0	...	35.3	49.4	20.8	28.6		
200	392	28.5	35.4	43.5	23.2	65.4		...	45.9	58.2	20.8	50.0	...	32.6	43.4	22.5	32.8		
300	572	26.1	33.9	41.3	21.0	64.0		...	45.0	57.0	22.4	51.0	...	29.4	42.7	20.8	32.8		
400	752	23.4	31.2	37.8	20.8	62.0		...	39.0	45.3	28.0	54.5	...	26.0	39.5	23.5	46.0		
500	932	...	...	32.7	16.8	56.6		...	...	24.5	47.0	87.0	...	...	34.1	25.0	55.4		
600	1112	...	...	18.8	20.5	67.0		...	...	10.08	61.5	95.0	...	...	28.2	28.0	61.0		
700	1292	...	...	12.1	36.8	85.4		...	...	4.87	60.3	97.0	...	...	17.2	40.0	74.0		
800	1472	...	...	5.04	45.6	91.5		...	...	2.82	88.0	97.0	...	...	12.0	51.0	79.0		
900	1652	...	...	...	...	...		...	...	...	...	...	...	...	6.02	70.0	81.0		
1000	1832	...	...	...	...	...		...	...	...	...	...	...	...	...	...	...

TABLE D.—Analyses and Heat Treatments of Steels Tabulated in Tables A, B, and C.

Heat Treatment:	0.14% Carbon Steel.	0.30% Carbon Steel.	0.42% Carbon Steel.	3% Nickel Steel.	Chrome-Vana- dium Steel.	3% Nickel- Chrome Steel.	14% Chromium Steel.	Silicon-Chrome Steel.	Nickel-Chrome- Tungsten Steel
	Normalised 920° C.	Normalised 900° C.	Normalised 900° C.	O.-H. 850° C. T. 630° C.	O.-H. 850° C. T. 640° C.	O.-H. 830° C. T. 600° C. O.-Q.	O.-H. 950° C. T. 760° C.	O.-H. 1075° C. T. 900° C. A.-C.	A.-C. 950° C.
Carbon . . .	0.14	0.32	0.42	0.32	0.43	0.29	0.27	0.60	0.40
Manganese . .	0.56	0.53	0.60	0.62	0.59	0.60	0.30	0.52	0.41
Silicon . . .	0.03	0.19	0.20	0.17	0.22	0.27	0.26	3.98	0.97
Sulphur . . .	0.043	0.017	0.016	0.017	0.039	0.0141	0.014	0.015	0.016
Phosphorus . .	0.04	0.017	0.016	0.022	0.034	0.018	0.021	0.017	0.016
Nickel . . .	0.16	0.09	0.49	3.07	0.32	3.41	0.42	0.23	10.31
Chromium . . .	...	...	...	0.07	1.14	0.89	13.30	8.75	13.65
Tungsten . . .	...	...	...	...	...	...	...	...	3.53
Vanadium . . .	...	...	...	...	0.18	...	...	...	...

O.-H. = oil-hardened; T. = tempered; O.-Q. = oil-quenched; A.-C. = air-cooled.

It will be seen that although 800° C. is a high temperature to have been selected, it is one which appears useful in displaying the character of the high tensile properties of the class of steels under consideration.

Considering the matter, therefore, from this simple point of view, a series of some forty-nine selected experimental steels becomes of interest.

In Tables I. to IX. will be found classified these different steels with the analyses and tensile test results placed alongside the results of tensile tests performed at 15° C. (normal temperature) and at 800° C.

Table I. contains the data relating to wrought iron, which is taken as the basis for comparison, mild carbon steel and examples of the ordinary high tensile alloy steels.

In Table II. will be found the results of an examination of the well-known type of silicon-chromium heat-resisting steel which has proved of service notably in the case of aero-engine exhaust valves.

In Table III. are given the results obtained from various examples of high-speed steel, which, as is well known, is frequently resorted to for the purpose of service at high temperatures. In this series will be found an example of cobalt-chromium valve steel.

Table IV. contains data of interest indicating the effect of approximately 14 per cent. of chromium when different percentages of carbon are present. A steel containing 18 per cent. of chromium is included for comparative purposes. The nickel present in this series is not intentionally there.

In Table V. will be found the results of an examination of three nickel steels of variable high nickel content, intended to disclose the influence of that element on the characteristics of the material at high temperatures.

Table VI. contains the results of a study of eleven steels based on approximately 14 per cent. of chromium, with a high and variable content of nickel, in some cases with tungsten, and the occasional addition of the other elements aluminium, molybdenum, copper, and cobalt. Variations of carbon are included.

Table VII. illustrates the results obtained from a series based upon 18 per cent. of chromium and approximately 8 per cent. of

TABLE I.—Analyses and Tensile Tests of Wrought Iron, Mild Steel, and Ordinary High Tensile Alloy Steels.

Steel No.	Material.	Analysis.										15° C.				800° C.		
		C. %	Mn. %	Si. %	S. %	P. %	Cr. %	Ni. %	Mo. %	Va. %	Condition.	Yield Point. Tons sq. in.	Max. Stress. Tons sq. in.	Elongation. %	Reduction of Area. per %	Max. Stress. Tons sq. in.	Elongation. %	Reduction of Area. %
1	Wrought iron	0.09	0.08	0.10	...	...	...	...	...	...	As forged	13.78	22.34	20.0	48.43	2.03	53.5	58.0
2	Mild steel	0.14	0.56	0.02	0.048	0.04	...	...	...	...	Normalised	19.50	27.2	38.0	61.0	4.0	75.0	98.0
3	3% Nickel	0.34	0.60	0.29	0.021	0.012	...	3.28	...	...	O.-H. 850° C.	32.2	50.7	23.3	59.2	5.37	52.0	82.2
4	3% Ni-Cr	0.29	0.60	0.27	0.014	0.018	0.89	3.41	...	...	T. 630° C.	48.8	57.8	24.0	63.6	5.60	74.3	78.0
5	Ni-Cr-Mo	0.30	0.57	0.24	0.010	0.015	0.61	2.38	0.59	...	O.-H. 850° C.	56.4	63.7	24.0	66.0	7.68	70.3	90.0
6	Cr-Va.	0.43	0.59	0.22	0.039	0.034	1.14	0.32	...	0.18	T. 620° C.	50.9	58.5	18.7	62.0	6.70	68.0	95.0
											O.-H. 850° C.							
											T. 650° C							

TABLE II.—Analyses and Tensile Tests of Si-Cr Valve Steels.

Steel No.	Material.	Analysis.				Condition.	15° C.				800° C.			
		C. %	Mn. %	Si. %	Cr. %		Yield Point. Tons per sq. in.	Max. Stress. Tons per sq. in.	Elongation. %	Reduction of Area. %	Max. Stress. Tons per sq. in.	Elongation. %	Reduction of Area. %	
7	Si-Cr valve steel	0.35	0.57	3.27	9.45	Annealed	52.0	70.0	13.0	20.5	6.05	66.5	99.0	
8	Si-Cr valve steel	0.57	0.42	4.07	8.5	Oil-hardened 1075° C, tempered 900° C, air-cooled	59.0	68.0	20.0	49.0	3.93	81.6	99.3	

TABLE III.—Analyses and Tensile Tests of High-Speed and Co-Cr Steels.

Steel No.	Material.	Analysis.						Condition.	15° C.			800° C.		
		C. %	Mn. %	Si. %	Cr. %	Ni. %	W. %	Mo. %	Va. %	Co. %	Yield Point. Tons per sq. in.	Max. Stress. Tons per sq. in.	Elongation. %	Reduction of Area. %
9	High-speed steel	0.55	0.24	0.23	3.36	...	14.75	...	0.47	...	...	47.45	21.6	38.7
10	High-speed steel	0.56	0.20	0.21	4.15	...	16.05	...	0.65	...	...	50.0	22.0	38.5
11	High-speed steel	0.54	0.22	0.39	4.08	...	18.0	...	0.84	...	28.3	51.6	16.6	27.5
12	High-speed steel	0.58	0.12	0.41	3.90	...	0.36	7.91	0.99	5.41	48.8	57.1	15.2	23.4
13	Cobalt-chrome valve steel	1.51	0.23	0.44	13.22	1.08	...	...	...	5.17	36.4	54.6	13.0	16.5
												

TABLE IV.—Analyses and Tensile Tests of Chromium Steels.

Steel No.	Analysis.					Condition.	15° C.				800° C.		
	C. %	Mn. %	Si. %	Cr. %	Ni. %		Yield Point. Tons per sq. in.	Max. Stress. Tons per sq. in.	Elongation. %	Reduction of Area. %	Max. Stress. Tons per sq. in.	Elongation. %	Reduction of Area. %
14	0.07	0.10	0.10	14.92	...	Fully tempered	18.0	31.0	40.0	74.26	3.05	77.6	99.8
15	0.09	0.39	0.37	18.52	0.26	Air-cooled 900° C.	19.0	28.6	16.0	...	3.0	81.5	...
16	0.16	0.30	1.31	14.04	...	Air-hardened 950° C., tempered 820° C.	...	37.4	27.3	64.0	4.53	49.0	92.14
17	0.31	0.30	1.16	13.17	0.32	Air-hardened 950° C., tempered 820° C.	31.0	45.0	28.0	60.9	5.79	76.8	83.3
18	0.36	0.12	0.26	14.66	0.30	Oil-hardened 950° C., tempered 600° C.	...	58.0	22.0	45.0	6.04	45.6	91.5
19	0.54	0.33	0.94	14.56	0.88	As received	32.8	54.6	25.5	54.3	9.30	80.0	87.0

TABLE V.—Analyses and Tensile Tests of Nickel Steels.

Steel No.	Analysis.					Condition.	15° C.			800° C.			
	C. %	Mn. %	Si. %	Cr. %	Ni. %		Yield Point. Tons per sq. in.	Max. Stress. Tons per sq. in.	Elongation. %	Reduction of Area. %	Max. Stress. Tons per sq. in.	Elongation. %	Reduction of Area. %
20	0.23	0.18	0.10	Nil	12.23	Air-cooled 950° C.	83.0	99.0	12.0	31.0	5.75	43.2	40.5
21	0.27	0.98	0.79	0.05	25.7	Air-cooled 950° C.	13.1	40.0	52.0	70.4	6.90	34.4	28.2
22	0.23	0.35	0.12	Nil	36.5	Air-cooled 950° C.	22.8	40.4	44.5	64.0	7.85	37.5	33.7

TABLE VI.—Analyses and Tensile Tests of 14% Cr Steels with Added Elements.

Steel No.	Analysis.										15° C.				800° C.			
	C. %	Mn. %	Si. %	Cr. %	Ni. %	W. %	Al. %	Mo. %	Cu. %	Co. %	Condition.	Yield Point, Tons per sq. in.	Max. Stress, Tons per sq. in.	Elongation, %	Reduction of Area, %	Max. Stress, Tons per sq. in.	Elongation, %	Reduction of Area, %
23	0.11	0.34	0.21	14.84	10.16	...	...	...	...	...	As rolled	24.6	45.2	52.0	68.1	10.17	46.4	44.0
24	0.29	0.29	0.17	14.08	11.90	...	...	...	...	...	Air-cooled 1150° C.	18.2	42.8	64.0	65.0	12.65	30.4	33.0
25	0.41	0.46	1.10	13.94	9.84	...	...	...	...	3.15	Air-cooled 1000° C.	24.2	46.4	9.0	12.6	13.10	37.0	68.5
26	0.34	0.33	1.18	13.80	8.44	...	1.06	1.44	...	...	Air-cooled 1000° C.	21.5	56.0	21.0	...	14.33	68.0	...
27	0.64	0.61	1.84	14.3	13.0	1.0	...	...	...	...	Air-cooled 1000° C.	35.6	56.4	22.0	31.5	12.5	52.0	67.0
28	0.55	0.73	1.45	13.10	12.78	2.3	...	...	2.58	...	Air-cooled 1000° C.	38.0	56.6	22.5	32.0	14.0	43.0	65.3
29	0.42	0.31	0.69	13.30	8.87	3.42	...	...	...	...	Air-cooled 950° C.	34.8	56.8	7.5	...	22.75	16.0	32.8
30	0.57	0.48	0.72	13.97	9.5	3.36	...	...	...	...	As forged	40.1	62.9	29.0	33.0	22.50	24.0	47.0
31	0.76	0.60	0.76	12.10	9.38	3.07	...	...	...	...	Air-cooled 1050° C.	28.4	57.0	11.0	11.0	15.4	54.0	71.2
32	0.61	0.67	0.4	14.94	10.36	5.94	...	...	...	1.91	Air-cooled 1000° C.	35.2	52.0	12.5	12.0	13.65	33.6	66.4
33	0.47	0.70	0.14	12.47	19.67	3.57	...	...	...	...	...	36.8	45.7	...	...	19.30	18.4	37.8

TABLE VII.—Analyses and Tensile Tests of 18% Cr Steels with Added Elements.

Steel No.	Analysis.							Condition.	15° C.				800° C.			
	C. %	Mn. %	Si. %	Cr. %	Ni. %	W. %	Mo. %		Yield Point. Tons per sq. in.	Max. Stress. Tons sq. in.	Elonga- tion. per %	Reduc- tion of Area. %	Max. Stress. Tons sq. in.	Elonga- tion. per %	Reduc- tion of Area. %	
34	0.13	0.13	0.56	17.88	7.74	...	...	17.5	48.6	55.0	39.17	7.48	10.4	14.5	
35	0.41	0.13	0.11	19.92	8.92	...	...	24.0	53.35	41.0	50.9	8.93	27.8	67.0	
36	0.34	0.48	0.85	18.51	7.78	3.09	...	35.2	70.0	10.0	...	21.3	...	...
37	0.38	0.68	1.21	18.72	9.74	3.27	...	29.2	50.6	27.5	28.9	20.0	41.5	59.0		
38	0.30	0.52	1.46	17.70	7.0	4.23	...	38.0	58.5	37.5	52.0	17.8	38.0	53.0		
39	0.58	0.36	4.0	15.54	8.14	...	...	...	70.0	20.0	...	15.25	68.0	71.8	
40	0.59	0.27	1.08	19.10	7.73	...	9.73	47.7	60.0	4.5	4.0	20.98	36.0	49.6		

TABLE VIII.—Analyses and Tensile Tests of Steels of Higher Cr Content with Added Elements.

Steel No.	Analysis.						Condition.	15° C.				800° C.			
	C. %	Mn. %	Si. %	Cr. %	Ni. %	W. %		Yield Point. Tons per sq. in.	Max. Stress. Tons per sq. in.	Elongation. %	Reduction of Area. %	Max. Stress. Tons per sq. in.	Elongation. %	Reduction of Area. %	
41	0.06	0.39	0.39	23.22	24.02	...	Air-cooled 1050° C.	18.8	39.6	48.0	67.0	13.2	33.5	38.4	
42	0.19	0.32	0.84	20.29	19.29	...	Air-cooled 1050° C.	33.2	49.0	35.0	49.0	17.37	8.0	17.0	
43	0.25	0.96	2.20	23.85	17.21	...	As received	49.2	56.4	20.0	27.5	15.0	23.0	46.0	
44	0.29	1.16	1.81	14.95	24.82	2.86	Air-cooled 1050° C.	24.2	47.7	35.5	50.0	19.58	24.0	51.0	
45	0.48	0.85	0.19	24.75	16.39	3.85	Air-cooled 1050° C.	30.0	48.6	29.0	35.0	15.57	60.0	57.7	
46	0.52	1.01	1.41	23.90	22.29	3.13	Air-cooled 1050° C.	33.8	53.2	26.0	31.0	16.55	40.0	49.8	

TABLE IX.—Analyses and Tensile Tests of 10–12% Cr Steels with Very High Nickel Contents.

Steel No.	Analysis.					Condition.	15° C.				800° C.		
	C. %	Mn. %	Si. %	Cr. %	Ni. %		Yield Point. Tons per sq. in.	Max. Stress. Tons per sq. in.	Elongation. %	Reduction of Area. %	Max. Stress. Tons per sq. in.	Elongation. %	Reduction of Area. %
47	0.35	1.36	0.21	10.9	35.15	As rolled	24.0	46.0	31.0	51.0	13.7	45.5	54.8
48	0.06	0.89	0.71	11.69	60.40	As rolled	...	...	...	...	12.25	40.0	38.5
49	0.81	1.50	0.58	12.8	66.0	As rolled	33.03	54.6	26.0	30.0	15.3	38.0	43.0

nickel, with and without tungsten, silicon, and molybdenum. Again, the influence of variable carbon content is included.

In Table VIII. will be found the data from steels containing, generally, in the neighbourhood of 20 per cent. of chromium and 20 per cent. of nickel, with and without tungsten, with variable carbon content.

Table IX. contains the results from alloys of 11 to 12 per cent. of chromium, in two cases with over 60 per cent. of nickel and variable carbon content, and one with 35 per cent. of nickel.

CONSIDERATION OF THE DATA GIVEN IN TABLES I. TO IX.

Wrought iron, it will be seen on reference to Table I., when pulled in tension at 800° C., gives a value as low as 2·03 tons per sq. in., and this is of interest as a basis of comparison for the steels under consideration, since it is a near commercial representative of pure iron. With 0·15 per cent. carbon steel a value of 4 tons is obtained, and the increased strength is most probably due to the carbon and manganese content. The other four steels in this table are typical of the modern high tensile hardened and tempered alloy steels, nickel, nickel-chromium, nickel-chromium-molybdenum, and chromium-vanadium. The highest value obtained at 800° C. is that given by the nickel-chromium-molybdenum steel with a maximum stress of 7·68 tons per sq. in. Thus it may be considered that in the ordinary steels employed in engineering, 7 to 8 tons per sq. in. indicates the limiting maximum stress value at 800° C.

Table II. discloses the very illuminating fact that the silicon-chromium heat-resisting steels are already softened so considerably by a temperature of 800° C. that values of only 4 to 6 tons per sq. in. are obtained. Table III. clearly shows that the high-speed tool steels tested only gave values ranging from 8 to 10·5 tons per sq. in., and the cobalt-chromium valve steel gave a value of 13 tons per sq. in., but was deficient in ductility.

It is of interest to turn now to the general data with a view to deducing the effect of the addition of some of the elements available upon the resistance to softening at high temperatures, as indicated by the tests performed at 800° C. If steels 14 and 15 in Table IV. are studied, the remarkable fact is disclosed that

with the carbon at 0·07 to 0·09 per cent., chromium contents of 14 and 18 per cent. respectively are without influence, since values are not obtained equal to the mild steel of commerce. In both cases a value of 3 tons per sq. in. is obtained. With the chromium stationary at 14 per cent., however, it is possible, by increasing the carbon to 0·54 per cent., to raise the strength at 800° C. to 9·30 tons per sq. in. As a matter of fact, the last steel has been successfully employed in large quantities as a heat-resisting steel, but it is clear that the increase in strength at the high temperature is due to the combined effect of the carbon and the chromium.

As regards the influence of nickel, it will be seen on reference to Table V. that in the case of the three steels Nos. 20, 21, and 22, the presence of nickel up to 36·5 per cent., even with 0·23 per cent. of carbon, does not give a value greater than 7·85 tons per sq. in.

With such data before us concerning the effect of chromium or nickel even when added in large percentages, it is instructive to study the effect when both elements are present together. The results obtained from Nos. 34 and 35, Table VII., indicate that with 18 to 20 per cent. of chromium and 8 to 9 per cent. of nickel, with a range of carbon from 0·13 to 0·41 per cent., values of only 7 to 9 tons per sq. in. may be expected. With carbon at 0·06 per cent., as shown by steel No. 41, Table VIII., a steel containing 23·22 per cent. of chromium and 24·02 per cent. of nickel gave a value of 13·2 tons, whilst with 0·11 per cent. of carbon, steel No. 23, Table IV., containing 14·84 per cent. of chromium and 10·16 per cent. of nickel, gave a value of 10·17 tons per sq. in., but with values indicative of much greater ductility at the temperature.

Attention should now be directed to the enhanced values obtained by adding tungsten to the chromium-nickel steels. Steels Nos. 29 and 30, Table VI., containing 13 to 14 per cent. of chromium, and 9 to 10 per cent. of nickel, with 3 to 4 per cent. of tungsten, give values of 22·75 and 22·50 tons per sq. in. Steels Nos. 36 and 37, with 18 to 19 per cent. of chromium and similar nickel and tungsten contents, give values of 21·3 and 20·0 tons per sq. in. Steel No. 44, Table VIII., containing 14·95 per cent. of chromium and 24·82 per cent. of

nickel, and nearly 3 per cent. of tungsten, gives a value of 19.58 tons per sq. in. It will thus be seen that the addition of tungsten results in a very marked increase in strength when added along with nickel and chromium. Values of 20 to 25 tons per sq. in. are obtainable with steels of this class compared with 2 to 3 tons from wrought iron and mild steel. This evidence would point to 14 per cent. of chromium being about the requisite addition required of that element, but that, as regards nickel, similar results are obtained over a wide range of composition.

Other results enable the deduction to be drawn that the addition of molybdenum (see No. 40, Table VII.), and to a lesser degree silicon (see No. 39, Table VII.), strengthens the iron-nickel-chromium steels at high temperatures.

Carbon plays an important part, and there is clearly an optimum percentage for the maximum strength in each combination in the alloys.

In concluding this section, the author would state that he realises that the data given naturally apply only to the particular condition of the steels and alloys when tested. He has reason to believe that the values obtained would be to some extent modified by varying the heat treatment accorded to the material. The data are, however, sufficiently defined and explained to make possible general deductions as regards the influence of the addition of the elements dealt with upon the strength at the temperature in question.

COMMENTARY.

The plan of the paper was designed to record the influence of modified composition upon the maximum stress value at a high and arbitrarily selected temperature. The author appreciates the limitations of the data given, but it is fully established from experience gained with steels under service conditions, that an ordinary tensile test at a high temperature enables a discriminating selection to be made of materials for such service. But before heat-resisting steels can be used by the engineer for working under conditions of high temperature, with the same economy of weight as in the most enlightened practice of to-day at ordinary tempera-

tures, much more information is required concerning their physical characteristics as affected by temperature.

It is, of course, obvious that data concerning the safe range of stress for materials at high temperatures must be provided, and, furthermore, that the method of providing them must be one that can be performed in a reasonable time, and they should be capable of reference back to fundamental and more refined and lengthy observations. The method adopted at the Brown-Firth Research Laboratories consists of deducing the safe stress by discovering by static loading the stress within which, at the temperature, stability of dimensions is attained within a period of 24 hours for a further period of 48 hours, with an extension not exceeding the elastic deformation by 0.5 per cent. on the gauge length with limitation as regards measurement for permanence of dimensions to 0.01 per cent. of the gauge length. Even such an arbitrary method requires a long time for the completion of the large series of steels for the whole range of temperature under examination. In due course, however, the author trusts to have the pleasure of presenting the data. In the meantime, the method employed, and its value in the direction indicated, can well form the subject of valuable discussion.

Turning now to the discussion of the general problem dealt with, the author would like to be able to give satisfactory explanations of—

- (1) Why the characteristics of steel are so modified with increasing temperature.
- (2) Why the added elements modify the properties of the steel at the high temperature in the manner disclosed.

The whole of the explanation turns upon an understanding of the nature of cohesion, and that again awaits the more complete elucidation of the nature of the atom and the electron. Whether this will help to produce materials of exceptional characteristics is problematical, because, even when our knowledge of the atom and its fields of force is complete, we shall still have to await the next phase, which obviously consists in understanding how to make use of that knowledge. Progress will probably take the same line as in the past, *i.e.* by experimentally determining, in a more or less empirical manner, the various

factors which affect the cohesive forces. It is, of course, extremely desirable to know many things. For instance, what determines the space lattice with which the various atoms crystallise ; why such different space lattices behave differently, as under the conditions dealt with in the present research ; the causes of different solubilities ; whether compounds can exist as such in solid solution ; a visualisation of the mechanism of the effect of the speed of application of stress.

As regards slip, the author has always been led to the conclusion that the smaller the crystals, the higher the resistance, owing to the multiplication of diverse orientations, whereas evidence would show that those steels have greatest strength at high temperature which consist of very considerable sized crystals, thus leaving the resistance to slip to be mainly due to interatomic forces in their effect in influencing the intrinsic resistance of individual crystals to slip and rupture.

With regard to (1), when a tensile test-piece is stressed, motion of the atoms in relation to one another takes place with the resulting elastic deformation. After passing a certain value of stress, plastic deformation occurs. This is associated with slip along certain planes, and the movement is constrained to the degree to which the progressive balancing of the effort applied in overcoming the interatomic forces has taken place. If the stress applied is high enough, deformation proceeds until rupture occurs. At higher temperatures the effort required to overcome the interatomic forces is less, owing to the modification in these forces with temperature. Under static loads, below the continuous creep limit, the test-piece will elongate elastically at first, and then plastically until the opposition, due to resistance to slip, balances the applied load. With greater loads the balance cannot occur, and the piece elongates until fracture takes place. Increasing temperature will decrease the resistance to slip, and hence "continuous creep" stress is lowered. With rapid loading, as in the case of a normal short-time tensile test, time is not allowed for the test-piece to develop the amount of deformation which for the temperature and stress would otherwise occur. In consequence, the load required to fracture is greater than in the case of continuous loading. The difference between the two increases with rise of temperature and with increase in the rate of

application of the load. The influence of the reduction of area of cross-section during the test must be considered as regards its influence in increasing the effective stress upon the material.

With regard to (2), in our actual present ignorance of the nature of slip, it is difficult to discuss the influence of the various elements introduced into the material. The author presumes—and indeed there is ample evidence that such is the case—that if the stress required to break the material at 800° C. under the ordinary tensile test is higher, then the elastic range and also the “continuous creep” stress are raised. Discussing, then, these general phenomena, it seems fair to postulate that the kind of atoms most likely to prevent slip, which is clearly the means by which improvements in these steels are made, would be those which, on account of the nature and magnitude of their fields of force, would cause most disturbance of the lattice. This would provide an influence operating at all temperatures, but modified by the mobility of the atoms coincident with the temperature. Unfortunately, the strength at high temperature bears little relation to the strength at low temperature. Nickel is an element with a similar atom to iron, and crystallises in the same manner at high temperatures; it would, therefore, not be expected to increase the strength at such temperatures much when added to iron. It is interesting to note, as is well known, that a critical percentage of nickel increases the strength of iron at ordinary temperatures fivefold; at 800° C. (see steel No. 20, Table V.) the effect of hardening is small. Chromium is an atom approximately similar to iron, and which crystallises with a body-centred configuration. Reference to the experiments (steels Nos. 14 and 15, Table IV.) will show that neither at ordinary temperatures nor at 800° C. does this element, even when present in large proportion, materially harden the steels, and yet it would appear to be of material help in providing great strength at high temperature. It might be deduced from the experiments that nickel had some little influence in hardening up the iron, but that chromium had less. The two elements together certainly resulted in making it necessary to apply a stress several times greater at 800° C. than in the case of iron. The addition of tungsten in relatively small quantities in the presence of the elements nickel and chromium, without carbon, has not been determined. If, however, the same

amount of tungsten is added to iron alone, the result is negligible, and, incidentally, if the tungsten is added with only chromium present, such is also the case ; likewise, if only nickel is present. One has, therefore, to consider that the effect to be explained is that tungsten added to iron in the presence of a sufficient quantity of nickel, chromium, *and carbon* produces this effect, yet, clearly, there is also an optimum carbon content. Now all that can be said is that tungsten is a heavier and larger atom, and the implication is that it should increase the strength of the iron, but why should it need a critical accompaniment of carbon, chromium, and nickel for strength at high temperatures, and why should its influence not be more marked at ordinary temperatures ? It would appear that its influence is most effective when added to alloys in which the iron throughout the whole range of temperature exists in the γ condition, the most successful of the steels being in the austenitic condition.

In conclusion, the author would like to record his appreciation of the liberal attitude of the directors of Messrs. Thos. Firth & Sons and Messrs. John Brown & Co. in permitting the publication of these results. He would also like to thank Mr. Stanfield, Mr. Clements, Mr. Woolman, Mr. McGregor, and other members of the Brown-Firth Research Laboratories Staff for their assistance in the carrying out of these researches.

DISCUSSION.

Mr. W. J. TALBOT (Walsall) congratulated the author on a paper full of information, most of which was new and all of which was of value. The paper was very interesting to him as a tube-maker, and, curiously enough, he had covered some of the same ground recently but to a lesser extent, and was very glad to say that his figures for both yield point and ultimate tensile strength at elevated temperatures agreed very closely with Dr. Hatfield's.

On p. 588 the author gave the ultimate tensile strength of 0.15 per cent. carbon steel as 4 tons at 800° C., but did not give the yield point. The bursting pressure of a tube depended not on the ultimate tensile strength, but on the yield point, the reason being of course that as soon as a tube started to yield and increase in diameter the stress on the tube walls got bigger and bigger as the tube got larger, and with a given internal pressure a tube would eventually burst after passing the yield point. For that reason it would be very valuable to have more information as to the yield point of mild and heat-resisting steels up to, say, 800° C. He had found that with mild steel at 800° C. the yield point was almost nothing, and therefore no matter how thick the tube might be the bursting pressure would also be almost nil.

On p. 580 the author showed that at 800° C. the maximum stress for his heat-resisting chrome-nickel-tungsten steel was 17.2 tons per sq. in.; his own figure was 18.4 tons, which was quite near enough, as it was very difficult to get a correct tensile test with temperatures of the test-piece as high as 800° C., but he found that the yield point was 4.8 tons at that temperature. That was, to his mind, a most important point; it meant that with that heat-resisting steel, tubes could be made from it, so that a 1½-in. × 10-gauge tube would give a bursting pressure of about 2000 lb. per sq. in. at 800° C., whereas a mild carbon steel, say 0.15 per cent., would have a bursting pressure of almost nothing.

Dr. W. ROSENHAIN, F.R.S. (National Physical Laboratory), wished to refer to a point dealt with in connection with Mr. Tapsell's paper on the previous afternoon, namely, the real meaning of the tensile figures which Dr. Hatfield gave. The last speaker had done a great service to the whole question by showing how those figures could be misunderstood, because he assured Mr. Talbot that if he relied on a tensile strength of 4 tons per sq. in. at 800° C. on that particular steel, and exposed it for any length of time to that kind of stress, it would certainly fail. The yield point determined in that way was not a reliable index of what the steel would stand indefinitely, and that was the real difficulty. He quite sympathised with Dr. Hatfield when he said that to have determined the true peak stress for 50 steels would have taken a very

long time, and if Dr. Hatfield or anyone else could show a quick road to the truth in that matter everyone would welcome it, but it must be a road to the real truth and not to something which was convenient as a figure, but not ultimately reliable.

Personally, he had not any actual figures for the particular steel to which Dr. Hatfield and Mr. Talbot referred, but the actual creep stress—that is, the stress which that particular material at 800° C. would stand indefinitely—would not be much more than something of the order of 2 tons per sq. in. It was probably correct, as Dr. Hatfield suggested, that if one had material “A” with a tensile strength, determined by pulling at a normal rate at 800° C., which was three times as great as that of a material “B,” material “A” would probably have a higher creep stress than material “B.” That was not quite certain, but it was probably true, and therefore as a very broad guide to the behaviour of materials at high temperatures there was something to be said in justification of Dr. Hatfield's figures. No doubt that was the justification Dr. Hatfield had in mind when he put them forward, and as far as they went they were valuable. He did not suggest that they should not have been put forward or were not worth having; until more were obtained they were interesting and useful as a guide to the materials which were worth thorough investigation from that point of view. Such an investigation was very necessary for two reasons, the first being the proved experimental fact that steel which had an apparent tensile strength of 10 or 12 tons per sq. in. and an apparent yield point of 4 or 5 tons might have a creep limit of only 2 tons. That had been found in a certain number of definitely proved cases, and gave one pause.

The second reason was a consideration of the manner in which the metals and alloys fail at high temperatures. As long ago as 1913 Mr. J. C. W. Humfrey and he (Dr. Rosenhain) presented a paper before the Institute which gave rise to one of those lively discussions for which the Institute was then famous. It described the mechanical properties of low-carbon steel at temperatures up to 1100° C., and above the A_3 point it showed that the results obtained depended entirely on the rate of loading. If the material were loaded quickly at a rate comparable with an ordinary tensile test, one got a comparatively high strength and great elongation. If, on the other hand, it were loaded very slowly, one got a very low strength and fracture by intercrystalline separation, practically without elongation. That, he thought, was one of the first examples of creep test, although it was a very quick creep test; it was not anything like as gradual as the creep tests which were made at the present time. It was, however, carried out at an excessively high temperature.

It was subsequently shown by the late Mr. Ewen and himself that every pure metal, if loaded lightly and slowly heated, would break by intercrystalline separation at a temperature quite appreciably below its melting point, showing that somewhere or other a stage was reached

where the intercrystal separation was easier than the deformation even of those very soft, hot crystals. At ordinary temperatures fracture occurred by breakage through the crystals, and undoubtedly at intermediate temperatures one had both phenomena in varying degrees, but the degree in which one thing or the other would occur depended, as was quite definitely known, on the rate of loading. Consequently, the properties which the materials displayed under an ordinary tensile test, when the load was applied in a few minutes or even a few hours, might be quite different in character and scale from what would occur when the load was very slowly applied or was so slight that yielding under it occurred at a very slow rate. That was why it was found possible, under certain conditions of loading and temperature, to get a state of affairs in which, he believed, even over several weeks, the rate of extension might be very slow indeed, and then it might suddenly increase and fracture might develop quite quickly.

He was not suggesting that this kind of failure would occur in a great number of cases, but care was needed. He realised fully that the engineer wanted his data quickly and wanted a reception test which could be made in a few minutes, or, at any rate, a few hours, but however urgently one might want to give the engineer that, and however urgently the engineer might need it, one must be sure that whatever test was used was fundamentally reliable, and until one knew the relationship between ordinary tensile figures, whether ultimate stresses or so-called yield points, and the creep limit, one must be very cautious in basing design on figures of that sort. He said "so-called yield points" because there was no true yield point at those temperatures. The creep limit was the true endurance test. The figures Dr. Hatfield gave were valuable, and they were data which were needed and might in some cases be interpreted. He hoped it might eventually be possible to interpret them all, but for the moment it was necessary to exercise considerable care.

Dr. H. MOORE, O.B.E. (Research Department, Woolwich), thought the series of tests on 49 different alloy steels, made by a simplified method at 800° C., did give a very useful set of comparative data. As Dr. Rosenhain had well pointed out, the data had to be taken with care and their limitations must be recognised, but he thought the results were valuable as giving a general survey of the properties at 800° C. of a large number of steels which were now available. The high tensile strength obtained with some of those special steels, up to 20 tons per sq. in. at 800° C., was quite remarkable.

As regards the tests on the 49 steels at 800° C., the method of carrying out the tests was described; only the maximum stress, the elongation, and the contraction of area were measured, and the rate of loading was given. The speed of pulling at the rate of $\frac{1}{4}$ in. elongation a minute was, within any elastic range which existed at that temperature, extremely rapid, though probably the conditions at the beginning of the

test were such as to reduce that speed of pulling very considerably owing to the stretching of parts of the testing machine itself. It was hardly possible to get that speed of elongation within the elastic range. However, a high rate of loading was adopted, and he asked whether the same conditions applied to the fuller tests reported in Tables A, B, and C, carried out through a range of temperature from 100° to 1000° C. In those tests figures were given for the limit of proportionality and the yield point, as well as the other properties. If the speed of pulling were the same, the elastic limit was reached very rapidly indeed, and he would like to know what sort of extensometer and testing machine were used. He thought that more information should be given about the method of carrying out the tests reported in Tables A, B, and C.

Professor H. C. H. CARPENTER, F.R.S. (Hon. Treasurer), wished to raise two small points. First of all, with regard to the temperature of 800° C. at which the high temperature tests were carried out, he would like to know whether it would not be the case that, at any rate with some of the alloy steels, that would be in the Ac_1 range. The point he had in mind was whether it were not possibly the case in some of the alloys that that temperature was in the transition zone between the α and γ states of the iron. If such were the case the properties of the steels would be affected in a way that did not occur in the case of steels whose Ac_1 range did not coincide with 800° C.

His second point was that he gathered that the best results, so far as the maintenance of maximum stress at 800° C. was concerned, were obtained with nickel-chromium-tungsten steels. He did not observe in Table VI., which gave those values in the tests carried out, any nickel-chromium-molybdenum steels except one which contained 1 per cent. of aluminium as well. He asked whether Dr. Hatfield had carried out any tests on nickel-chromium-molybdenum steels, comparable with those carried out on nickel-chromium-tungsten steels. He had in mind the very valuable properties of such steels in regard to temper-brittleness, and possibly it would be found that they would repay investigation in connection with the author's present purpose.

Mr. A. P. HAGUE (Chesterfield) congratulated the author on putting forward some most valuable data. At the present time engineers, both mechanical and chemical, were using materials under higher pressures and at higher temperatures, and at the same time were exposing those materials to the attack of various chemical reagents. They were going ahead very rapidly. Meanwhile our knowledge of creep stress seemed a long way behind, and therefore to give the engineer any idea of what were, or were likely to be, suitable materials, some short test appeared absolutely necessary. He thought the test used by the author was a very good one, provided it was known under exactly what conditions it was carried out. If one knew the conditions one could, he thought,

get a very good comparison of the different materials available. If the chemical engineer had to wait until the creep stress limit of all the various steels he might use were definitely known, he would get tired of waiting.

The present position with regard to heat-resisting materials was very similar to what it was some time ago with regard to ordinary materials. The engineer designing a crankshaft knew nothing about fatigue limit some years ago, but he used the maximum stress in conjunction with a factor of safety and produced a crankshaft which did the job. He thought Dr. Hatfield's figures might be likened very much to that; instead of the fatigue limit being required it was the creep stress that was needed, and he suggested that if the engineer used the high-temperature strength figures given in the same way that he formerly used the maximum stress, and designed on a factor of safety which he could choose for himself, the paper would be a very considerable help to him.

There was another point. Assuming the chemical engineer had creep stress figures, he would be no better able to choose definitely the best material than he was when using Dr. Hatfield's figures, because he would still have to take into consideration the effect of the attack of the gases on the steel. The factor of safety necessary to allow for the attack of the gas was much greater than that which he would have to take to cover the difference between the figures given by Dr. Hatfield and the creep stress. He thought, therefore, that Dr. Hatfield's figures were a very valuable contribution to our present knowledge of the subject.

Dr. J. H. PARTRIDGE (Wembley) remarked that only those who had been engaged on a study of the properties of materials at elevated temperatures could realise the amount of work entailed in the author's investigation. As pointed out by Dr. Rosenhain and Dr. Moore, it was difficult and tedious to obtain reliable data on the strength of alloys at elevated temperatures, owing to the effects of creep. For example, creep would be more pronounced in the case of the silicon-chrome steel No. 8, which has an elongation of 81 per cent. when tested at 800° C., than in the case of nickel-chrome steel No. 28, which has an elongation of only 43 per cent. under similar conditions. Nevertheless the results obtained by Dr. Hatfield were very valuable in so far as they indicated the relative merits of the various steels when tested under the conditions described, and they enabled the engineer to choose steels suitable for very severe industrial conditions.

In an investigation on valve steels carried out under the direction of Mr. A. R. Page, it was found that when test-pieces were pulled at the rate of 1 in. extension in 16 minutes—one-quarter of the rate adopted in the present investigation—the results were lower and therefore more correct than those obtained when higher pulling speeds were employed. The differences were sometimes as much as 40 per cent. Apparently

data on the strength of alloy steels published by the manufacturers must have been the results of tests in which a rapid rate of loading was adopted.

He considered that 800° C. was a well-chosen temperature at which to test these alloys, but he hoped that the author would be able to extend the work and carry out tests from 400° to 900° C.

It would also be valuable to carry out brittleness tests at high temperatures, for in the work in which he was concerned it had been found that, whereas a certain silicon-chrome steel gave an impact value of 20 ft.-lb. at ordinary temperatures, the value was 118 ft.-lb. at 100° C. Further, that increase in toughness was maintained up to 800° C., and supplied a reasonable explanation of the fact that valves made of this particular steel seldom broke in service. That decrease in brittleness was confirmed repeatedly, and was found to be a linear function of the temperature from -12° to 100° C.

He also hoped that the author would extend the work to include machinability tests. Whereas a nickel-chrome steel containing 13 per cent. each of nickel and chromium was not very hard, it was exceedingly tough, and although it possessed very good mechanical properties at elevated temperatures silicon-chrome steels were often used because they were much easier and cheaper to machine.

CORRESPONDENCE.

Professor J. H. ANDREW (Glasgow) wrote that the author was to be congratulated upon his excellent contribution to our metallurgical knowledge. Was he (Professor Andrew) correct in assuming that in every case in which a steel gave a high figure for maximum stress at 800° C., the steel was essentially austenitic in character? If that assumption were correct, it suggested to him that it would be of interest to determine whether or not the fractured ends of the pulled test-pieces were magnetic. What he had in mind was this: a steel, which under conditions of stress might tend to become martensitic, would certainly do so when pulled at normal temperatures. Martensite represented, as compared with austenite, an expanded state, or state of less density. According to the principle of Le Chatelier, when a material was subjected to tensional stresses the natural tendency would be for the steel to stretch in order to reduce the tensional forces. If it became martensitic by doing so, the expansion or stretching would be greater, therefore, if the possibility of a change from austenite to martensite existed, and the change would be brought about in accordance with physical laws. Pure nickel steels when cold-worked became martensitic when the original unworked condition was austenitic (up to a certain percentage of nickel). Nickel steels, he noted, did not give a high maximum stress

at 800° C. Were the fractured ends magnetic? It was to be expected that martensite would give low stress values at high temperatures.

Whilst these remarks were of a speculative nature, the author would no doubt agree that if it were possible to state definitely that an austenitic steel which remained austenitic after fracturing would invariably give a high maximum stress figure, it would simplify matters, and be of some aid in the selection of materials to withstand high stresses at elevated temperatures. Such a conception, were it proved to be correct, would, moreover, be the outcome of the author's most excellent work.

Mr. T. H. BURNHAM (London) wrote: Dr. Hatfield has presented a useful and informative paper, but as it deals only with short-time tensile tests the scope claimed is rather too inclusive. There are many other mechanical properties at high temperatures which are of great importance to engineers and designers, but Dr. Hatfield only refers somewhat casually to work in these directions, promising to give his results in a subsequent paper.

Whilst the data presented are no doubt of considerable theoretical interest, a doubt may be expressed as to how far they will be of service in practical application, as it is generally agreed that the design of equipment for high-temperature work should be based on the strength of materials at their operating temperature over a long period of time. Short-time tests also cannot be expected to give useful data with respect to metals which fail from intercrystalline cracking under long exposure to high temperature. Dr. Hatfield has measured the proportional limit of many of the steels investigated. Without entering into a discussion whether there is any such mechanical property at high temperatures, it may be said that it is only of interest if the circumstances of design and use of equipment admit of no deformation whatsoever under load. In the absence of this desideratum it appears best to base design on the fatigue limit or creep strength, whichever is the lower.

With reference to the proportional limit data given in the paper, which appear to be rather high in comparison with data on similar steels obtained by other workers, it should be borne in mind that the determinations depend on the sensitiveness of the instruments and the accuracy of the testing layout. As an example, it was found by one observer that the proportional limit of stainless iron was 38 tons per sq. in. at 400° C., but on replacing the extensometer by one with forty times greater accuracy, the proportional limit was reduced to 18.5 tons per sq. in. Moreover, errors of alignment of the specimen of 0.01 per cent. introduced errors of the order of 15 per cent. The proportional limit at high temperatures also depends on the speed of the test. The matter is further complicated by the strain-hardening of ordinary steels up to about 500° C.

If the tensile test results at 800° C. given by Dr. Hatfield are

arranged in order of merit, it will be noted that the strongest steels—the twelve at the top of the list—are nickel-chromium steels containing tungsten or molybdenum. It would appear that credit for the observance and use of this effect should be given to the well-known metallurgists of the Commentry Fouchambault Co. at Imphy.

Dr. Hatfield makes some interesting remarks as to why these complex steels possess the maximum recorded breaking loads. The fundamental explanation will no doubt be forthcoming in due course from the physicists, but it may be remarked as significant that these steels are of the austenitic type, not subject to grain growth, and are work-hardened at temperatures up to 900° to 1000° C. Moreover, atoms of the heavy metals like tungsten may be those which most disturb the lattice planes, and so prove most capable of acting as pegs to prevent slip.

In the latter part of his paper Dr. Hatfield suggests a method for deducing the safe static stress. A need for standardised conditions of determining creep stress for purposes of comparison has long been felt. It may be remarked that the time necessary to attain steady viscous conditions depends on the temperature, the load, and the section of the test-piece. It does not appear to need 24 hrs. for steels, at the temperature chosen, to settle down to a steady plastic state, and the permissible extension in two days suggested by Dr. Hatfield seems rather too high to be taken for the safe loading conditions. All concerned will, however, be indebted to Dr. Hatfield for bringing forward this point, as it is of fundamental importance in enabling comparison to be made between the results of the various workers on this subject.

Dr. R. HAY (Glasgow) wrote that the author's paper formed a very important addition to our knowledge upon the high-temperature properties of steels. If the metallurgist was to meet the ever increasing demands of the engineer for improved mechanical properties at elevated temperatures, then a clear understanding of the mechanism which brought about the improvement was of first-rate importance. The present paper went a long way in supplying the necessary data for the formulation of such a view.

The data on the plain carbon steels revealed that even in the case of steels in the normalised condition there was a marked sequence of changes on tempering at increasing temperatures. Generally the yield point and the maximum stress showed a decrease followed by a very marked increase as the tempering temperature was raised, that increase amounting, in the case of the 0.30 per cent. carbon steel, to 10 tons per sq. in. in the maximum stress. It would be of interest to know if Dr. Hatfield had carried out similar tests at intervals of temperature closer than 100° C., or on steels in the quenched state.

A brief analysis of the results obtained by the author in the high-temperature tests of the special alloy steels was of great interest.

Kinzel¹ showed that in Fe-Cr alloys the γ phase entirely disappeared at 12.37 per cent. of chromium. Alloy 15 might be considered as a simple Fe-Cr alloy, which at 800° C. would exist as a single homogeneous phase—with the body-centred lattice—giving a maximum stress of 3 tons per sq. in. In alloy 19 there existed practically the same condition so far as iron and chromium were concerned, but there was also present 0.54 per cent. of carbon. According to Grossmann,² this alloy would have a body-centred lattice with free carbide; Westgren's paper on the Fe-Cr-C system suggested the same thing. The maximum stress in that case was now 9.3 tons per sq. in. The increase in the value of the maximum stress was most probably due to the dispersed carbide particles reinforcing the simple phase. Prolonged soaking at 800° C. might cause those carbide particles to coalesce, with a corresponding drop in the maximum stress figure. It would be of great interest if the author could supply figures showing the time/maximum-stress relationship for that steel at 800° C.

Cobalt was very soluble in the body-centred iron lattice, so that in alloy 13 it was probable that the body-centred lattice was again the basis, and throughout it were dispersed the carbide particles. The increased maximum stress value of 13.0 tons per sq. in. was in keeping with the increased carbon content of 1.51 per cent., and would appear to indicate that cobalt had little direct effect.

Alloy 22 contained 36.5 per cent. of nickel, which amount would render the γ phase stable from the solidus to below room temperature under all conditions. Unfortunately that alloy also contained an appreciable percentage of carbon, and although carbon was soluble in the γ -iron phase, yet with so much nickel present it was probable that some of the carbon would be present as free carbide. Alloys 20, 21, and 22 bore out the contention that with constant carbon and increasing nickel, the carbide content would increase, since nickel rendered the carbon less soluble. It was thus possible to account for the high maximum stress value of alloy 22 by the increased amount of carbide present rather than by attributing it to the type of lattice structure, namely, the face-centred lattice.

Now, with chromium above 12 per cent. the body-centred lattice was the stable one, and with nickel above 30 per cent. the stable phase had a face-centred lattice; therefore with certain percentages of iron, nickel, and chromium both types of lattice might be expected to be present. From Bain and Griffiths' work³ it appeared that the addition of a small percentage of nickel required a large amount of chromium to maintain the body-centred lattice as the stable phase, and that the alloys containing both nickel and chromium in the paper under

¹ *American Institute of Mining and Metallurgical Engineers, Technical Publication, No. 100.*

² *Transactions of the American Institute of Mining and Metallurgical Engineers, 1927, vol. lxxv. p. 214.*

³ *Ibid.*, p. 166.

discussion lay in the region of the face-centred lattice, that is, a single phase area. Alloys 23, 24, 47, and 49 formed an interesting series. The carbon content increased from 0.11 to 0.81 per cent., and the maximum stress at 800° C. increased from 10.17 to 15.3 tons per sq. in. That again suggested that the increased strength was due to the dispersed carbides—complex carbides in this case.

Sykes' work¹ showed that molybdenum and tungsten were much more soluble in α -iron than in γ -iron, and that there was a great change of the solubility of the compounds in the α phase at different temperatures. In alloys 36, 40, and 44 the percentages of nickel and chromium were such that the face-centred lattice appeared to be the stable phase. Therefore it was probable that the iron-tungsten or iron-molybdenum compounds (or the complex iron-tungsten-carbon or iron-molybdenum-carbon compounds, as appeared more probable from the work of Westgren and Phragmén²) were not in solution, but dispersed throughout the alloys, so causing the increased strength. Sykes' work showed that those compounds did not readily coalesce even at high temperatures, and it should be expected that those alloys would prove more stable than the others when subjected to prolonged heating at 800° C. It was probable that Dr. Hatfield could give some definite information on that point.

Alloys containing a high chromium content, about 40 to 50 per cent., and a low nickel content, 5 to 10 per cent., would seem worthy of attention, and possibly the author might at some future date add still further to our knowledge by studying some of those alloys at high temperatures. In that range Bain found a constituent which he called "B," and which changed in solubility with changing temperature. He said: "By suitable means of precipitation, the hard 'B' constituent can be made to strengthen the already stiff alloy matrix in the manner of submicroscopic particles, as exemplified in duralumin or by Sykes' Fe-W and Fe-Mo alloys." Above 850° to 950° C. that constituent went into solution, and therefore hardening ceased above those temperatures.

On p. 592 the author stated, "Those steels have greatest strength at high temperature which consist of very considerable sized crystals." That suggested that a single phase existed in those alloys from the temperature of the solidus down to room temperature, thus resulting in large grains. That was in agreement with what was said above. The strength of the alloys came from the dispersed carbides—chromium carbides, tungsten-iron carbides, and molybdenum-iron carbides—in the uniform matrix.

¹ *Transactions of the American Society for Steel Treating*, 1927, vol. x. p. 839 (Fe-Mo system); *Paper read before the American Institute of Mining and Metallurgical Engineers*, Feb. 1926 (Fe-W system).

² *Transactions of the American Society for Steel Treating*, 1928, vol. xiii. p. 539.

This paper was also presented at the adjourned meeting held in Sheffield on May 10, 1928. The following remarks are extracted from the discussion which took place :

Professor C. H. DESCH (Member of Council) said that members were greatly indebted to the author and to the firms which he represented for so frankly putting before them a statement as to the properties of so large a number of steels, with their chemical compositions. It might well be that these facts were well known to those who were concerned in the manufacture of heat-resisting alloys, but they were certainly not familiar to most metallurgists, and the information was very valuable. He could not help thinking that the author had not been quite fair in his quotation from Dickenson's paper on flow at high temperatures. It must be remembered that Dickenson's paper was a pioneer one, and there was not sufficient evidence at the time for a definite conclusion on several points. It seemed natural at the time to suppose that stress at ordinary temperatures, if continued long enough, would cause flow, but since that date there had been an immense amount of experimental work by Professor Lea and many others, which went to show that for every temperature there was a limiting creep stress, as it was sometimes called, below which flow would not take place. At atmospheric temperatures that stress was too high for flow actually to occur. The author had prepared a careful review of work on the whole subject, which was omitted for lack of space, but in his theoretical discussion he had written as if such work had never been conducted. The knowledge of creep at present went far beyond the stage assumed in the paper.

Mr. S. A. MAIN (Sheffield) said that as regards the large number of data contained in the paper, these confirmed generally the knowledge of the strengths of heat-resisting steels and their relative characteristics already in existence. His remarks, however, would be directed more particularly to the author's suggestion of an arbitrary test, by which it was intended to determine the safe working stress for any particular steel.

His opinion was that such a test, while serving to classify various steels, quite failed as a means of selection between two steels of the best types, and for a particular application. The test was arbitrary in several respects, including the temperature at which it was conducted and the permissible amount of stretch. The same test carried out at an appreciably higher or lower temperature would in some cases show a different order of quality in a series of steels. Whatever the kind of test adopted, it must of course be applied over the range of practical temperatures.

As regards the permissible amount of stretch, it would also be found that on a basis of, say, 0.25 or 0.75 per cent. permanent set, that would

again result in a different order of quality in some cases. The actual stress figures obtained in those cases for any one steel would also be appreciably lower or higher respectively, and therefore it could not be said that a figure based on an arbitrary extension of 0.5 per cent. indicated, as claimed, the safe working stress.

He appreciated the great difficulties of establishing criteria for the strength of heat-resisting steels at their working temperatures, and sympathised with those who, like the author and himself, had this to deal with as a practical problem. He thought, however, that, laborious, delicate, and lengthy as was the present means of determining actual creep stress, there was no other available of any practical use. The author's method really obtained a measure of that propensity of heat-resisting steels known as "initial creep," and left untouched the real question of their subsequent behaviour of "steady creep," which could not be determined in a 3-day test.

Dr. W. H. HATFIELD, in reply, said that, before replying to the discussion in detail, he would make two observations. In the first place, he had provided a bibliography of the subject, which, owing to the exigencies of the moment, had not been published. He was sorry, because in the bibliography he gave a complete account of the development of the subject by other investigators; he mentioned the matter by way of an apology for the omission of the names of eminent research workers who had contributed to the particular field in question.

The discussion on the method of testing and the characteristics of the materials in question was, in a way, rather beside the point, because on p. 591 he was at pains to point out that he fully realised all that had been said about tensile tests. He had a suggestion to make, namely, that a reliable method of sorting out with nearness to the actual conditions was to be found by preparing a number of test-pieces and stressing them on the tensile testing machine under those conditions. The load was put on so as to determine the stress which did not, over a period of 24 hrs., produce an extension exceeding 0.5 per cent. of the length of the test-piece and which, for the next 48 hrs. after the first 24 hrs., did not produce any further extension in the length of the test-piece within the accuracy of measurement, which he put at $\frac{1}{10,000}$ in. If one obtained that value that was a complete answer. He said that in all seriousness, having made himself fully aware of the work which was being done on creep, and he himself had been doing a good deal of work in that field. That was a complete answer to any objections put forward, but even so the values he obtained under that test, some of which he had mentioned in a previous discussion, must be used by engineers and metallurgists with real intelligence and with an appreciation of the test and what it really meant. The subject was a very difficult one. If one were to wait and not use heat-resisting steels in important structures and parts until the scientific investigator could give the real creep value of the material, then, as Mr. Hague had

said, one would have to wait a very long time, and technology and engineering would be put back for years. He hoped that the suggestion he had made would be taken very seriously; it was an attempt to provide a way out of the difficulty, and he made the attempt because his companies were very much interested, not only in the heat-resisting steel question, which was quite a minor one, but in the bigger problems of high temperature and high pressure steam. What he was postulating in the paper was also intended to deal with that question, and he hoped the technical world would consider it very carefully.

Mr. Talbot's remarks were of much interest, since he was actually engaged in producing industrially products from materials such as those under consideration. He (Dr. Hatfield) much appreciated the information which Mr. Talbot had put forward, and which confirmed his own data in a very interesting way. There was just one point to which he desired to draw attention, namely, that the stressing of those materials at high temperatures must be done with a full knowledge of what the material was actually capable of. In the paper it was pointed out that at 800° C. under the ordinary tensile test the best heat-resisting steels would be broken at a stress of 20 to 25 tons per sq. in., but that under long applications of the load comparatively small stresses would cause rupture, and that it was not wise to legislate for stresses being carried indefinitely if they exceeded 2 tons per sq. in. Mr. Talbot's instance of a 1½-in. 10-gauge tube should be very carefully reconsidered, because a pressure of 2000 lb. per sq. in. would result in a stress of about 5 tons per sq. in., and at a temperature of 800° C. such a stress would obviously lead to gradual deformation and rupture of the tube. However, as Mr. Talbot justly pointed out, tubes of such material could carry stresses of an entirely higher order than would be the case with mild steel tubes in such ranges of temperature.

He (Dr. Hatfield) very much appreciated Dr. Rosenhain's contribution, and there did not seem to be any point upon which the author and he disagreed, except perhaps the interpretation which they were disposed to put on the manner in which the test figures were obtained. He (Dr. Hatfield) was, however, determined in this instance, at any rate, to convert Dr. Rosenhain from his point of view completely. He was quite satisfied that the mass of evidence which they were steadily accumulating at the Brown-Firth Research Laboratories would clearly indicate that it was unnecessary to wait five months before one could attain useful and reliable information as to the stresses required to produce plastic flow in materials at high temperatures.

Dr. Moore raised several points with regard to the manner of testing. The form of extensometer used was a simple lever type, which he would have much pleasure in showing to Dr. Moore when he was next in Sheffield, and the tensile testing machine was the Olsen multiple-lever type.

It was quite true that in selecting an arbitrary temperature like 800° C., one created the difficulty, as pointed out by Professor Carpenter, that some steels were undoubtedly in the α range and some were in

the γ range; some were, no doubt, very near to the transition zone. He (Dr. Hatfield) quite agreed with Professor Carpenter that complete comparison of the several steels was only possible with tests done over the whole range of temperature. As regards the effect of molybdenum, there was one steel in Table VII.—No. 40—which showed the effect of nearly 10 per cent. of molybdenum on the chromium-nickel steel, and it was to be inferred from that result that molybdenum had a similar effect to tungsten. It should, however, be borne in mind that molybdenum, from an industrial point of view, increased the cost of the steels.

He (Dr. Hatfield) very much appreciated Mr. Hague's comments, who, it was quite clear, looked at the subject from a similar angle to himself. Mr. Hague, like himself, often had to endeavour to provide materials to meet practical conditions, and it was gratifying to find that he approved of the attempt made to deal with the problem of plastic deformation over extended periods.

He (Dr. Hatfield) very much appreciated Dr. Partridge's remarks, and particularly for his pointing out the very important fact that certain steels which have low impact values at ordinary temperatures give high values with small increases of temperature. Generally speaking, he was in complete agreement with Dr. Partridge's observations.

Professor Andrew's suggestive contribution was particularly valuable, and he would certainly give every consideration to the ideas which he had put forward.

He thanked Mr. Burnham for his kind remarks; on several points they were agreed. It was, however, quite clear that any attempts to utilise the data given in the paper for purposes of design should be governed by a knowledge of the true meaning of the figures. The extent to which the Commentry Fourchambault Co. at Imphy had contributed to the development of the heat-resisting steels was well known and required no emphasis. The bibliography to which he (Dr. Hatfield) had previously referred included such information as that Company had thought fit to publish.

To Professor Desch he was particularly indebted for the definite statement that for every given steel, flow would not take place below a given temperature. That statement entirely corroborated the point of view which he (Dr. Hatfield) had expressed in the paper, but, unfortunately, it was erroneous for either Professor Desch or anyone else to state that, at the present time, that had been established by unquestionable experimental data. Up to the present time, determinations had not been made of a sufficiently sensitive type to make it possible to say arbitrarily which point of view was correct; hence the interest of a discussion such as the present one.

He (Dr. Hatfield) noted Mr. Main's view of his proposed short-time test, but felt that with the passing of time Mr. Main would be a convert to his view.

With regard to Dr. Hay's comments, which were very constructive, it was evident from alloy 15 (18.5 per cent. chromium, 0.09 per cent. carbon) that chromium in solution in α -iron at 800° C. had little or no influence on the maximum stress. The increased strength of alloy 19 (14.6 per cent. chromium, 0.54 per cent. carbon) could therefore only be put down to two causes: (1) The strengthening action of free carbides (that alloy was probably hypereutectoid); or (2) the material was in the γ condition at 800° C. The latter was unlikely, although there was nearly 1 per cent. of nickel also present.

There were no data as to the solubility of carbon in ferrite containing nickel, but it was known that the solubility in the high nickel-chromium austenitic steels at 800° C. was extremely small. The hypothesis advanced, that the slightly increased tenacity of the higher nickel steels was due to the greater amount of free carbide on account of the reduced solubility, rather than to the high nickel content *per se*, had, therefore, some kind of support. However, alloy 48 (60 per cent. nickel, 11 per cent. chromium, 0.06 per cent. carbon) could hardly be expected to have any free carbide, yet it gave 12.25 tons maximum stress. It would therefore appear that nickel had a slight influence *per se* in increasing the strength at 800° C.

The alloys 23, 24, 47, and 49 certainly were an interesting series, but carbon was not the only variant. Their analyses were as follows:

Alloy.	Carbon. %	Manganese. %	Silicon. %	Chromium. %	Nickel. %	Maximum Stress at 800° C. Tons per sq. in.
23	0.11	0.34	0.21	14.8	10.2	10.17
24	0.29	0.29	0.17	14.1	11.9	12.65
47	0.35	1.36	0.21	10.9	35.15	13.7
49	0.81	1.50	0.58	12.8	66.0	15.3

There were, however, many alloys which did not fall in with this series, thus:

Alloy.	Carbon. %	Manganese. %	Silicon. %	Chromium. %	Nickel. %	Maximum Stress at 800° C. Tons per sq. in.
34	0.13	0.13	0.56	17.9	7.7	7.48
35	0.41	0.13	0.11	19.9	8.9	8.93
39	0.58	0.36	4.00	15.5	8.1	15.25
41	0.06	0.39	0.39	23.2	24.0	13.2
42	0.19	0.32	0.84	20.3	19.3	17.4

Therefore, whilst he agreed with Dr. Hay that the presence of free carbides had an important bearing on the maximum stress results at 1928—i.

800° C., it was impossible to dissociate its effect from the varying influence of other elements present.

Dr. Hay's contention as to the influence of tungsten and molybdenum had a certain measure of support from the behaviour of magnet steels, in which at temperatures in the γ region (about 800° to 950° C.) a tungsten carbide (simple or complex) was formed, which was only sparingly soluble in the γ matrix. His (Dr. Hatfield's) opinion was that those carbides coalesced fairly readily at temperatures of about 800° C. There was evidence from Swan's paper,¹ however, that silicon retarded the coalescing power.

Many of the results were very difficult to explain on a simple theory—for instance, the comparatively low results on alloys 45 and 46, the difference between 37, 39, 44, and 45, &c.

There was very little information on the very high chromium-nickel steels.

¹ This *Journal*, pp. 369–377.

CHROMIUM STEEL RAILS.¹

BY THOMAS SWINDEN, D.MET. (SHEFFIELD),

AND

P. H. JOHNSON, ASSOC.M.INST.C.E. (DERBY).

Introduction.

It is much to be regretted that there is still no laboratory or workshop test that provides a reliable result concerning resistance to wear. Several types of machines are available, and some interesting results have been obtained, but, due no doubt to the complex nature of the physical characteristics involved, and also to the wide range of conditions affecting wear in service, such data must still have only a limited acceptance. This is particularly unfortunate in the case of steel rails for permanent way, and the only method of obtaining reliable information is to observe test rails under service conditions for years, and to test the wear by weighing or by accurate measurements of the profile.

Correlative data as between behaviour in service on the one hand, and physical tests, chemical composition, and microstructure on the other, are no doubt available to the engineers in charge of our large railways, and the wider dissemination of such information would be of great advantage in promoting greater interest in, and research upon, the subject which must ultimately result in benefit to the user. It is therefore with great pleasure that the authors record their thanks to H. P. Miles, Esq., Divisional Engineer of the London Midland and Scottish Railway, Midland Division, for permission to communicate in these notes certain data concerning the behaviour in service of a quantity of special chromium steel rails supplied to the Midland Railway some 13 years ago.

Consideration of space has prevented the inclusion in this paper of an historical sketch of the development of rail steel, but it is well known that during the last 20 years the British Standard

¹ Received December 28, 1927.

Specifications, and also those of many of our large railway companies, for bull-head railway rails have been amended. The trend of development has been towards a harder rail, and this has been sought by increasing the carbon content. At the same time, the manganese maximum has been reduced, and as the bulk of the rails in this country are now produced by the basic open-hearth process, this has led to the fixing of a lower maximum for sulphur and phosphorus.

The advisability of asking for increased hardness (in this case "hardness" being obviously interpreted as "resistance to wear by abrasion") by increasing the carbon range and reducing the maximum manganese permitted is not beyond doubt. It is well known that at least certain large users formerly permitted makers to supply with manganese even up to 1.20 per cent. in acid Bessemer steel, with carbon up to 0.50 per cent. in ordinary and 0.55 per cent. in "higher-carbon" steel, and no untoward result has been forthcoming.

It would appear to be rather drastic, therefore, to limit manganese to 0.80 per cent. max. in to-day's specifications, and, in the authors' opinion, there is small room to doubt that better results from every standpoint would be obtained by taking manganese at least up to 0.90 per cent. (and preferably 1.0 per cent.), even if the carbon maximum were slightly reduced. If the carbon were reduced, it would no doubt be considered possible to increase the phosphorus limit somewhat.

This opinion is evidently not universally accepted, and in America, for example, the adherence to a high-carbon and low-phosphorus rail is still followed.

Nevertheless, the authors' view is that manganese should not be regarded merely as an element the amount of which should be limited to the minimum at which sound steel can be produced, but as a valuable alloying element to increase the resistance to wear with less danger than the corresponding increase in carbon.

A reconsideration of the British Standard Specification on these points has lately been advocated in an able article.¹ There is no doubt that an increase of 5 per cent. in the resistance of rails to abrasive wear would mean a very large economy, although the authors are inclined to regard the writer's estimate of this (which

¹ *Railway Engineer*, July 1927.

is given as over £100,000 in the cost of track materials alone to British railways) as somewhat exaggerated. Moreover, the authors are not in complete accord with the writer of the article, when he states that "the desired solution is not the costly alloy, nor even the heat-treated rail, but the correct composition of the rail itself." The tests quoted later indicate very definitely that an alloy (chromium) steel which can be produced at a reasonable commercial price has very distinct claims towards the solution of this problem.

Turning now to special steels, no doubt the most widely known and used "special" steel is the manganese steel discovered by Sir Robert Hadfield, and first described by him in 1888.¹ This material, containing approximately 1 per cent. of carbon and 13 per cent. of manganese, has remarkable wearing properties, advantage of which is taken in numerous directions where great resistance to abrasion is required.

Certain difficulties are naturally encountered in machining this class of steel, and it can scarcely be considered to be in the same category as "ordinary" or "chromium" steel described in this paper. It might be mentioned, however, in passing, that chromium steel crossings tested against *cast* manganese steel crossings have given surprisingly good results.

The improvement of rail steel by heat treatment suggested by Stead in 1898, and successfully developed by Sandberg, is well known, and the later experiments at the Neuves Maisons works and elsewhere are being followed with interest. It is suggested that an enhanced value of heat treatment is obtainable by careful selection of the composition, and that manganese and chromium should play an important part in the design of the most suitable steel.

Chromium Steel Rails.

In October 1913 arrangements were made for the production of a special rail which, whilst being sufficiently tough in the rolled condition, capable of being drilled and planed without difficulty, and free from adverse air-hardening properties, would give an economically advantageous life in the form of switches and crossings. Several casts of steel were made by the acid

¹ *Minutes of Proceedings of Institution of Civil Engineers*, 1888, vol. xciii. p. 61; *Journal of the Iron and Steel Institute*, 1888, No. II. p. 41.

TABLE I.—*Tests on Acid Bessemer Chromium Steel Rails.*

Section : M.R. 100 lb.

Blow.	Analysis.					1-ton Falling Weight Test; bearings, 4 ft. 3 in. apart.												Tensile Test.			
	C. %	Mn. %	Si. %	S. %	P. %	Cr. %													B.S.S. Piece.	Maxi- mum Stress, Tons per sq. in.	Elonga- tion, %	Reduction of Area, %
A.B. 1	0.51	0.84	0.214	0.049	0.047	1.02	Hght. of fall (ft.)	12	12	12	12	12	12	12	12	12	unbroken	D	60.6	8.0	11.6
" 2							Defl. (in.)	1.1	2.0	3.0	3.8	4.7	5.6	6.6	7.7	unbroken					
							Hght. of fall (ft.)	7	20	12	12	12	12	20	unbroken						
							Defl. (in.)	0.5	2.0	2.7	3.4	4.0	4.6	6.2							
B.B.	0.49	0.85	0.180	0.035	0.061	0.95	Hght. of fall (ft.)	12	12	12	12	12	12	12	12	unbroken	D	58.4	11.0	16.2	
							Defl. (in.)	1.5	2.5	3.7	4.9	6.0	7.3	8.7							
C.B.	0.52	0.88	0.214	0.037	0.053	0.99	Hght. of fall (ft.)	12	12	12	12	12	12	12	12	unbroken	D	60.8	9.0	14.0	
							Defl. (in.)	1.2	2.2	3.2	4.0	4.9	5.8	6.8							

Bessemer process containing varying amounts of chromium up to 2 per cent. A chromium content of approximately 1 per cent. was adopted as being most satisfactory, and some typical results of 3 casts of acid Bessemer chromium steel rails are given in Table I.

The ingots rolled well into 100-lb. M.R. section rails and were hot-sawn, cold-straightened, drilled and milled (where necessary) without difficulty.

It will be noted that the aggregate foot-tons in the falling weight tests are respectively 96, 95, 84, and 84, and the test-piece was unbroken in each case.

Some representative tests of carbon steel rails are given later, but, by way of rough comparison, it may be noted that the specification governing 100-lb. rails at that time was that 3 blows of a tup weighing 1 ton falling from 12 ft., using bearings 4 ft. 3 in. apart (aggregate, 36 ft.-tons), should give a deflection not exceeding 5.5 in. The usual quality acid Bessemer carbon steel rails gave about 5.0 in. The chromium steel rails at the same point gave 3.0, 3.7, and 3.2 in. respectively.

These results were sufficiently promising to warrant service tests being carried out, and the whole of the rails were put into service under such conditions as would test out, as severely as possible, the wear-resisting value. Reports on this follow later in the paper.

Influence of Reheating and Cooling in Air.

Full section test lengths of cast A.B. were reheated and cooled normally in air from temperatures of 400° to 800° C. in order to

TABLE II.—*Influence of Reheating and Air-Cooling on Acid Bessemer Chromium Steel Rail.*

No.	Heated to— ° C.	Tensile Test.		
		Maximum Stress. Tons per sq. in.	Elongation. % on 3 in.	Reduction of Area. %
1	400	59.4	8.0	10.4
2	500	62.2	8.5	11.6
3	600	60.48	8.5	11.6
4	700	59.55	11.0	19.18
5	800	61.44	10.5	20.8

TABLE III.—*Tests on Acid Open-Hearth Chromium Steel Rails.*

Cast.	Analysis.						Section.	Falling Weight Test.						Tensile Test.				Brinell Hardness taken from—Tensile Piece.		
	C. %	Mn. %	Si. %	S. %	P. %	Cr. %		Deflection after Consecutive Blows of 1-ton Tup falling from—						B.S.S. Piece.	Max. Stress, Tons per sq. in.	Elongation, %	Reduction of Area, %		Yield Stress, Tons per sq. in.	
								6 ft.	18 ft.	18 ft.	In.	In.	In.							In.	12 ft.
A	0.50	0.78	0.220	0.033	0.032	0.99	R.B.S. 90 lb.	In. 0.6	In. 2.5	In. 4.2	In. 6.1	In. 7.1	unbroken	D	61.52	14.0	31.6	36.2	277	Head
B	0.51	0.83	0.176	0.030	0.037	1.01	"	0.6	2.4	4.2	6.0	7.1	"	D	59.92	15.5	36.7	37.2	277	"
C	0.49	0.81	0.170	0.029	0.033	0.90	"	0.7	2.6	4.5	6.4	7.5	"	D	59.80	14.0	31.6	31.1	269	"
D	0.47	0.82	0.150	0.035	0.034	0.91	"	0.6	2.5	4.4	6.2	7.1		D	60.07	13.5	26.8	31.96	269	"
E	0.49	0.85	0.249	0.039	0.035	0.80	95 lb.	0.6	2.4	4.0	Unbroken			D	57.38	14.5	27.4	32.86	258	"
F	0.53	0.78	0.269	0.035	0.040	1.09	"	0.45	2.0	3.3	Unbroken			O	57.44	15.5	27.6	37.24	258	"
G	0.54	0.75	0.274	0.032	0.045	0.91	"	0.55	2.2	3.7	Unbroken			D	63.40	9.5	12.8	37.00	286	"
H	0.55	0.78	0.250	0.035	0.039	1.00	"	0.55	2.1	3.4	Unbroken			D	64.40	11.5	18.4	39.56	290	"
I	0.53	0.85	0.250	0.043	0.039	0.92	"	0.45	2.05	3.5	Unbroken			D	64.76	14.5	32.6	38.26	292	Foot
							"	0.55	2.2	3.7	Unbroken			D	59.00	10.25	15.2	36.10	266	Head
							"	0.55	2.1	3.4	Unbroken			D	60.60	15.0	33.6	36.84	272	Foot
							"	0.55	2.1	3.4	Unbroken			D	60.90	12.5	23.0	36.56	273	Head
							"	0.45	2.05	3.5	Unbroken			D	62.42	13.5	34.6	38.70	281	Foot
							"	0.45	2.05	3.5	Unbroken			D	61.26	11.25	20.8	36.70	276	Head
							"	0.45	2.05	3.5	Unbroken			D	62.86	15.0	27.4	39.00	282	Foot

¹ Rail reversed in drop test and given 3 consecutive blows from 18 ft.; unbroken.

REMARKS.

Falling Weight Test.—The test-piece 5 ft. 0 in. long is placed in a horizontal position with head uppermost upon two steel bearers standing 3 ft. 6 in. apart, and having their upper surfaces curved to a radius of 3 in. The blows are delivered by a tup weighing 20 cwt., the radius of the striking end of which is 5 in., striking midway between the bearers.

Tensile Tests.—B.S.S. test-piece O has an active gauge length of 2 in., and original diameter 0.564 in. D has an active gauge length of 3 in., and original diameter 0.798 in.

Brinell Test.—The values for casts E to I are calculated from the maximum stress results (factor, 0.225).

TABLE IV.—*The Influence of increasing Carbon Content on Acid Open-Hearth Chromium Steel Rails.*

Cast.	Analysis.					Falling Weight Test.										Tensile Test.				Brinell Hardness of Tensile Piece.				
	C. %	Mn. %	Si. %	S. %	P. %	Cr. %	Section.	Deflection after Consecutive Blows of 1-ton Tup falling from—										B.S.S. Piece.	Max. Stress. Tons per sq. in.		Elongation, %	Reduction Area, %	Yield Stress, Tons per sq. in.	
								7 ft.					12 ft.											12 ft.
								In.	In.	In.	In.	In.	In.	In.	In.	In.	In.							
J	0.51	0.90	0.260	0.040	0.041	0.94	R.B.S. 95-lb.	0.7	2.6	4.2	5.2	6.1	7.0	unbroken	C	59.20	18.0	39.2	39.40	269				
K	0.57	0.89	0.234	0.038	0.035	0.99	"	0.6	2.3	3.8	4.6	5.3	"	"	C	63.80	16.0	36.4	41.40	286				
L	0.61	0.95	0.236	0.039	0.037	0.97	"	0.5	2.1	3.5	4.1	Broke	...	"	C	65.12	11.0	18.4	45.60	293				

determine whether any adverse effect would result from heating a rail for bending. The tests showed a slight gradual improvement in ductility as the reheating temperature rose. (See Table II., p. 615.)

As the sources of supply of Bessemer steel were becoming more and more limited, the next step was to make a series of casts of similar steel by the acid open-hearth process. In Table III. (p. 616) are given a series of tests on acid open-hearth chromium steel rails.

The outstanding feature of the tests is the toughness under the falling weight tests, having in mind the comparatively high tensile strength. The attention of railway engineers is particularly directed to the higher tensile strength and Brinell hardness than is customary in the normal carbon steel rail, some representative data concerning which are given in Table VI. (p. 621). There is every reason to suppose that the service tests will be at least equal to those of the acid Bessemer chromium steel rails.

Influence of Increased Carbon Content in Chromium Steel Rails.

As a matter of interest, Table IV. (p. 617) is included, illustrating, on 3 further casts of acid open-hearth chromium steel rails, the influence of carbon up to 0.61 per cent., with other elements constant.

Influence of a Simple Heat Treatment.

The wear of the nose and knuckle of a crossing determines the life of the crossing, and certain methods have been used from time to time to improve ordinary quality rails by case or potash hardening.

By way of experiment, a length of rail was reheated to 950° C. and subjected to an air-blast on the head for 7 minutes, during which time the temperature of the surface of the head fell to 550° C. The result of this test is shown in Table V.

The depth of effect of the simple air-blast cooling of the head is important, and the following Brinell hardness tests show clearly that the head is fairly uniformly stiffened.

Position.	Brinell Hardness.
$\frac{1}{8}$ in. under surface of head	288
Centre of head	286
Centre of web	277
Centre of foot	269

It will be noticed that the foot is slightly softened by the process, and this effect is brought out in the deflection test. Thus, after the third blow, the deflection was rather greater on

TABLE V.—*Acid Open-Hearth Chrome Rail.**Analysis.*

C.	Mn.	Si.	S.	P.	Cr.
0.51	0.83	0.176	0.030	0.037	1.01 per cent.

Section.—90-lb. R.B.S. Test length, 5 ft. 0 in.; bearings, 3 ft. 6 in. apart; weight of tup, 1 ton.

Falling Weight Test.						Tensile Test.				Brinell Hardness of Tensile Heads.
Height of Fall (ft.)	6.	18.	18.	18.	12.	Max. Stress. Tons per sq. in.	Elongation % on 3 in.	Reduction of Area. %	Yield Stress. Tons per sq. in.	
Deflection, in. (as rolled)	0.60	2.40	4.20	6.00	7.10	59.92	15.5	36.7	37.22	277
Deflection, in. (treated)	0.55	2.25	4.15	6.20	7.45	62.64 59.06	13.5 15.0	29.4 33.6	41.10 ¹ 38.46 ²	286 265

¹ Head.² Foot.

the treated than on the untreated rail, due to the fact that the foot elongated and contracted in width after the manner of a ductile steel in tensile test after passing the yield point.

Figs. 1 and 2 (Plate XLI.) are micrographs illustrating the microstructure of the untreated rail, and Figs. 3 and 4 show the microstructure of the treated rail. Attention may be drawn to the following features :

The chromium steel "as rolled" (Figs. 1 and 2) shows a dense sorbitic pearlite matrix with a fine broken network of ferrite, the surface structure being somewhat finer than the interior. The heat treatment has reduced the quantity of free ferrite, but has preserved the sorbitic nature of the pearlite. Thus, the effect of the chromium addition, from a metallographic viewpoint, is to reduce the proportion of the soft ferrite constituent and to emulsify or "sorbitise" the carbide, both of which features contribute to the greater hardness and toughness of the chromium steel, as demonstrated in the tests of physical properties.

Typical Carbon Steel Rails.

In Table VI. is quoted a short series of tests which are regarded as typical of many hundreds of their respective classes. In making comparison with the chromium steel rails note should be taken that, so far as falling weight tests are concerned, the conditions of test are not uniform, owing to specification requirements, nor are the sections constant. The tests do illustrate, however, in a clear way the gradual increase in hardness in later years, referred to in the Introduction, and it is the correlative data concerning the wear of rails of these different grades which would provide such interesting information, particularly on the relative importance of carbon, manganese, and silicon content, and on the respective merits of the three classes of steel referred to.

Before turning to the service reports, it may be noted in connection with chromium steel rails that one very important factor to the railway engineer is the loss of sectional area due to corrosion, and also the wear of the foot of the rail due to contact with the seat of the chairs. This is especially important in badly ventilated tunnels, and a steel of greater strength and greater resistance to wear is of considerable advantage in such situations.

Service Reports on Chromium Steel Rails.

Reverting to the actual service of these chromium steel rails, it will readily be understood that a considerable period of time must elapse before data as to relative wear are available concerning the supplies of rails of the open-hearth quality, the supply of which commenced about 1921. The authors are indebted to the courtesy of H. P. Miles, Esq., Divisional Engineer of the Midland Division, London Midland and Scottish Railway, for the following data concerning the 100-lb. Bessemer chromium rails, and the following is extracted therefrom :

1.—*Service Reports on Acid Bessemer Chromium Steel Crossings.*—Sufficient steel was made to produce rails for eight complete crossings with point, splice, and wing rails, each 24 ft. long. The crossings were of various angles, and were laid in such places that the maximum amount of data might be obtained in regard to the properties of resistance to wear.

CHROMIUM STEEL RAIL. AS ROLLED.



FIG. 1.—Surface of head.



FIG. 2.—Centre of head.

CHROMIUM STEEL RAIL. HEAT-TREATED.



FIG. 3.—Surface of head.



FIG. 4.—Centre of head.

The above micrographs were taken at 100 diameters, and have been reduced to four-fifths linear in reproduction.

TABLE VI.—A Selection of Tests on Carbon Steel Rails.

Year.	Quality.	Analysis.				Section.	Bear-ings. Ft. in.	Falling Weight Test.				Tensile Test on Head of Rail.				Brinell Hard-ness Num-ber. ¹	Remarks.
		C. %	Mn. %	Si. %	S. %	P. %		Deflection after Consecutive Blows of 1-ton Tup.				B.S.S. Test-Piece.	Max. Stress, per sq. in.	Elon-gation, %	Re-duc-tion of Area, %		
1914	Bessemer acid	0.46	0.90	0.092	0.052	0.046	4 3	Hght. of fall (ft.) 12	12	12	12	D	45.5	18.0	26.0	215	
"	"	0.51	0.95	0.092	0.055	0.050	"	Defl. (in.) 2.1	4.0	5.8							
1915	"	0.45	0.90	0.068	0.051	0.052	3 6	Hght. of fall (ft.) 12	12	12	12	D	51.5	15.0	21.0	232	Higher carbon
	"						L. & Y. 95 lb.	Defl. (in.) 1.7	3.2	4.6							
1919	O.-H. acid	0.45	0.92	0.068	0.047	0.050	4 3	Hght. of fall (ft.) 12	12	12	12	D	44.8	19.5	29.4	202	
1920	"	0.47	0.86	0.108	0.052	0.043	3 6	Hght. of fall (ft.) 7	"	"	6.0	D	46.1	17.3	24.1	208	
"	"	0.55	0.95	0.052	0.040	0.052	4 3	Defl. (in.) 0.95	3.5			D	50.74	14.7	19.7	228	Higher carbon
"	"	0.53	0.88	0.110	0.038	0.037	3 6	Hght. of fall (ft.) 7	20	"	4.7	D	51.30	14.0	18.6	231	Higher carbon
1919	"	0.46	0.89	0.100	0.044	0.046	3 6	Hght. of fall (ft.) 7	20	3.1		D	45.0	20.0	30.6	203	
	"					L. & Y. 95 lb.		Defl. (in.) 1.0	3.5								
1920	O.-H. basic	0.49	0.86	0.060	0.039	0.019	3 6	Hght. of fall (ft.) 7	20			D	46.9	16.0	20.8	211	
1915	"	0.46	0.91	0.065	...	...	"	Defl. (in.) 1.0	3.6			D	46.7	15.3	...	210	
1913	"	0.46	0.90	0.062	...	...	"	Hght. of fall (ft.) 7	20	3.9		D	44.8	15.7	...	202	
1923	"	0.60	0.80	0.162	0.033	0.034	"	Defl. (in.) 1.0	3.4			D	53.3	13.0	18.6	240	
1913	"	0.52	0.84	0.268	...	...	"	Hght. of fall (ft.) 7	20	3.0		D	51.2	14.0	...	230	Sandberg
1920	"	0.57	0.93	0.246	0.024	0.035	"	Defl. (in.) 0.9	2.75			D	51.50	15.0	24.4	245	Sandberg
1925	"	0.55	0.73	0.150	0.030	0.040	"	Hght. of fall (ft.) 7	20	20	12	D	47.0	18.5	29.4	212	
1925	"	0.63	0.77	0.174	0.031	0.031	"	Defl. (in.) 1.0	3.1	4.1	5.1	D	53.8	14.5	21.6	243	Higher carbon

¹ The Brinell hardness values in the above table are calculated from the maximum stress, using a factor of 0.222.

There is no satisfactory method of testing, physical or mechanical, which represents even approximately the conditions which are to be met with in the permanent way. Cuttings, embankments, subsoil, drainage, and other considerations all tend, separately or conjointly, to produce results which are not always expected, and the very best materials may give only moderate satisfaction if there is any neglect in maintenance.

One of these crossings was laid at the departure end of an open station, where the bulk of the trains are brought to a stop, but a certain number of important passenger trains run through the station within a 30 miles an hour speed restriction. At this particular station there is a deep bed of clay, also coal workings, and the line is in a cutting. In consequence of this, it is not a simple matter to maintain efficient drainage, and periodically the crossing timbers would "work" as the greasy clay penetrated through the ample supply of ballast. This crossing gave a better life than a 0.55 per cent. carbon Bessemer steel, but the increase in life was not considered altogether satisfactory.

Another crossing laid at the entrance to a very busy station is, on the other hand, exceeding the most sanguine expectations, the life of the high carbon Bessemer steel crossing being $2\frac{1}{2}$ years, whereas the chromium crossing has already had a life of $13\frac{1}{2}$ years and is not yet worn out. See particulars in (b) below.

Another crossing at the same station but on the departure lines had a life of $6\frac{1}{4}$ years against 2 years' life of the 0.55 per cent. carbon Bessemer steel. This particular crossing was considered the most important on account of the heavy traffic it had to bear, and its life is considered to be conclusive evidence of the efficiency of this class of steel. See particulars in (a) below.

A further crossing in an important passenger line junction has had a life of $12\frac{1}{4}$ years, whilst the remainder of the junction has been replaced a second time during that period. See particulars in (c) below.

A trailing crossing in a main line junction, where trains are passing over regularly at a speed of 70 miles an hour, is wearing so well that the decrease in depth per annum can only be obtained by using the vernier caliper.

Further experiments are worth contemplating for the use of this steel in tunnels, or any point where the rate of wear and corrosion greatly exceeds the normal. The toughness under the falling weight test is an indication of its safety, and for point and crossing work its great advantage is the absence of any difficulty in machining.

2.—*Actual Wear of Chromium Steel in the Line.*—(a) A 1-in-11 trailing crossing manufactured out of blow B.B. (Table I.) was laid in at Derby on May 24, 1914, at a place where the life of an ordinary steel crossing was not more than two years. The latest report of September 30, 1919, says that the nose of this crossing has worn down about $\frac{3}{8}$ in., and the life to date is 5 years 5 months. Taken out August 1920. Total life, $6\frac{1}{4}$ years.

(b) A 1-in-8 facing crossing manufactured out of blow B.B. was also laid in at Derby on May 24, 1914, at a place where the life of an ordinary steel crossing was not more than $2\frac{1}{2}$ years. The latest report says that this crossing is wearing satisfactorily, the life to this date being $13\frac{1}{2}$ years.

(c) A 1-in-10 facing crossing manufactured out of blow A.B. has been in service in the up-line at St. Paul's Road passenger junction, London, for $12\frac{1}{4}$ years. It was laid in March 1914, and taken out in June 1926, thus showing 148 per cent. longer life than an ordinary steel crossing taken out at the same place.

General Remarks.—Although this steel is exceptionally hard, we did not find it much more difficult to plane than our higher carbon steel. This steel is also so tough that it is practically impossible to break it under any ordinary testing conditions.

This steel can be reheated for bending and cooled in air without any adverse effect in the same manner as ordinary steel, and, therefore, can be drilled and manipulated by a gangster on the line as required.

The data given in the above report will probably appeal to railway engineers more than the test data previously submitted, and should, it is suggested, encourage a deeper interest in the use of special steel for this purpose.

Chromium Steel Fishplates.

In May 1925, at the authors' suggestion, a quantity of acid open-hearth chromium rail steel was rolled into fishplates and tested. It is not proposed to go into details concerning the results obtained, but a few figures may be quoted as a matter of interest.

The tensile tests were of the following order :

Yield stress, 37 tons per sq. in. ; max. stress, 60 tons per sq. in. ; elongation on 2 in., 15 per cent. ; reduction of area, 36 per cent.

Joints were made using chromium steel fishplates with both ordinary and chromium steel rails, and the results were compared with joints built with ordinary steel fishplates and both qualities of rail steel. All were of the 95-lb. R.B.S. section. The joints made using chromium steel plates were naturally very much stronger.

Tested on 2-ft. centres, joints built with ordinary plates gave a set of 0·07 in. at 20 tons load, whereas 37 tons was required to produce the same amount of set with chromium steel-plated

joints. Tested on 3 ft. 6 in. centres, ordinary steel joints showed a set of 0·01 in. after a load of $7\frac{1}{2}$ tons, whilst chromium steel joints withstood 15 tons before sustaining the same amount of set.

The joints were built up with a $\frac{3}{8}$ -in. gap, and in each case the loading was continued until the heads of the rails touched. On the 2-ft. bearings, this load was 60 tons in the case of the chromium steel plates, the joints being sound; the deflection under load was 0·99 in. and permanent set 0·75 in.

There is probably a field worth developing with a view to strengthening the joint by the use of a stronger plate, and the tests indicate briefly what may be expected in this direction, although it is not suggested that the chromium steel is necessarily the most economical type of steel to employ for this particular purpose.

Summary.

1. The gradual development of steel rails of greater and greater hardness is briefly noted, and the advisability of relying essentially on an increase in carbon content for this purpose is questioned.

2. Test results and permanent way experience of a quantity of chromium steel rails are quoted, showing that there is every prospect of a useful future for such material where heavy duty is encountered.

The authors cordially acknowledge their thanks to the staff of Messrs. Samuel Fox & Co., Ltd., Stocksbridge Works, near Sheffield, by whom the work described herein was carried out, and to the company for permission to publish the data concerning manufacture and testing.

DISCUSSION.

Colonel N. T. BELAIEW, C.B. (London), referred to a point, perhaps of minor importance, relating to the illustrations. Figs. 1 and 2 gave the structures of the untreated rails, and Figs. 3 and 4 of the treated. The authors explained that that structure was "a dense sorbitic pearlite matrix with a fine broken network of ferrite." It seemed to him that in that particular case much higher magnifications were advisable in order to see the difference to which the authors referred. He suggested a magnification of at least 1000 diameters; it would then be possible to make calculations, to show what the influence of the heat treatment was. He (Colonel Belaiew) had made some calculations, not on the rails with which the authors dealt, but on Sandberg rails (carbon steel rails treated by the Sandberg process), and for the untreated specimens his calculations showed that the distance between the plates of carbide, the distance which he called Δ_0 , was about 500 $\mu\mu$ in one case and 300 $\mu\mu$ in another, a $\mu\mu$ being a micro-millimetre, one-millionth part of a millimetre. For the same rails in the treated condition the actual distance between the carbide plates was only 100 $\mu\mu$ in the case of the first sample and 120 $\mu\mu$ in the other. He thought that a magnification of 1000 or 1200 diameters would also make possible the calculation of Δ_0 for the chromium steel rails before and after treatment. Before treatment, of course, the direct process must be used for calculating the distance between those plates, and after treatment the indirect process, as indicated in his papers. A comparison could then be made of the distances between the plates in chromium rails and in carbon rails, after the application of the same process; the authors' thesis would, he thought, be borne out, that it was insufficient and not always advisable to use only carbon steels, and that chromium, and perhaps some other elements too, *in conjunction with suitable heat treatment*, were needed for a very good and efficient rail. He thought that was an important point, which could be proved not only qualitatively but quantitatively by the calculations he had suggested.

Mr. J. H. WHITELEY (Consett) asked whether the authors considered that the addition of chromium to steel for making rails to the extent they advocated was better as regards resistance to wear than the so-called sorbitising processes. A curious defect sometimes appeared in sorbitised rails known as the "grey spot." It appeared in the fracture, and he had no doubt the markings were really due to internal fractures or hair cracks in the steel brought about by the rapid rate of cooling. Could the authors say whether the use of chromium obviated that defect?

He agreed with the authors that manganese was a very valuable element in rail steel. In considering the effect of manganese, he had sometimes wondered whether it would be possible to increase the manganese content in the head of the rail to, say, 1.5 per cent. by suspending a piece of manganese steel sheet at the side of the mould. If that could be done a sorbitised head would be obtained with normal rates of cooling. He had had no opportunity of testing that out, but perhaps someone engaged in the manufacture of rails might feel inclined to try it.

Mr. A. P. HAGUE (Chesterfield) said that on p. 612 the authors referred to the question of manganese and to the present limit of 0.8 per cent. He did not think there was much room for doubt that the addition of manganese to steels containing over 0.5 per cent. of carbon was a better way of increasing the hardness than by adding carbon. An increased hardness was obtained whether manganese or carbon were added, but manganese appeared to produce considerably more toughness for any given hardness. He supported the authors' plea that manganese in rail steel be allowed up to 1 per cent., and that it was better to put a definite high limit on the carbon than on the manganese.

With regard to the heat treatment of rails, he thought considerable improvement might be made both in carbon steels and chromium steels by suitable heat treatment, but treatment of any sort of steel containing over 0.50 per cent. of carbon was always a dangerous job, and he thought it would be better to get the increased resistance to abrasion chemically rather than thermally.

In Table I. the authors gave a series of tests on chromium steel rails made by the acid Bessemer process, and on p. 615 they pointed out that whereas the usual quality of acid Bessemer carbon steel rails gave a deflection of about 5.0 in., the chromium steel rails at the same point gave 3.0, 3.7, and 3.2 in. respectively. Personally, he thought that was to be accounted for almost entirely by the yield point of the material. The authors had not given the yield point of the Bessemer 1 per cent. chromium rails, and he would be glad if they could say what it was. He thought that on an ordinary Bessemer rail the yield point would be in the neighbourhood of 28 tons per sq. in.; in the present case he thought the yield point was nearer 38 tons per sq. in.

In Table III. figures were given from a series of tests, including tensiles taken from the head and the foot. Could the authors explain the very big difference in reduction of area often found, and shown in the present instance, between the head and the foot? In one case the figure was 12.8 per cent. reduction from the head, and 32 per cent. from the foot. In any case it would appear that as the rail stood up very well under the tup, 13.2 per cent. reduction was ample for the job although it looked low, and, since many people measured ductility by the reduction of area, probably 13.2 per cent. was a good figure to keep in mind when considering rails.

Mr. H. HILLS (York) said Mr. John Miller, the engineer of the north-eastern area of the London and North Eastern Railway, had experimented with chromium steel rails, and had asked him to give the following particulars. Chromium steel switches and crossings had been in use in that area since April 1923, but only to a very limited extent and purely for experimental purposes. The first consignment of about 50 tons of chromium steel rails was obtained in April 1922; their chemical analysis and physical tests were as follows:

Analysis.

		%
Chromium	. . . . .	0.710
Carbon	. . . . .	0.576
Manganese	. . . . .	0.900
Silicon	. . . . .	0.252
Phosphorus	. . . . .	0.030
Sulphur	. . . . .	0.034

Falling Weight Test.

Bearings 3 ft. 6 in. apart.

Fall. Ft.	First Piece. Deflection. In.	Second Piece. Deflection. In.
7	$2\frac{3}{8}$	$\frac{5}{8}$
20	$2\frac{7}{16}$	$2\frac{1}{8}$
15	$3\frac{5}{8}$	$3\frac{3}{16}$
15	$5\frac{1}{8}$	...
15	Not fractured	...

Tensile Test.

Ultimate breaking stress	. . .	59.4 tons per sq. in.
Elongation in 3 in.	. . .	14%
Yield stress	. . .	31 tons per sq. in.

Those chromium steel rails were manufactured into switches and crossings for use at the east end of Newcastle Central Station, being laid down in April 1923 in electrified lines carrying very dense traffic. It was found that the life of some of the switch blades was prolonged to $2\frac{1}{2}$ years by the use of chromium steel, as compared with 11 months for ordinary steel to the British Standard Specification.

As regards the remainder of the chromium steel switches and crossings laid down at the same place, recent reports indicated that they would give double the life of switches and crossings of ordinary steel. He regretted that he had no information regarding the process of manufacture of that small consignment, the rails being supplied from stock.

A further consignment of 200 tons of open-hearth chromium steel

rails was obtained in January 1924; the analysis and physical tests were as follows :

L.N.E.R. Analysis.

	%
Chromium	1·11
Carbon	0·520
Manganese	0·700
Silicon	0·257
Phosphorus	0·032
Sulphur	0·041

The rails were drop-tested to British Standard Specification, each test-piece being given an additional blow with a fall of 18 ft. without fracture.

Tensile Test.

	First Piece.	Second Piece.
Ultimate breaking stress	63·4 tons per sq. in.	59 tons per sq. in.
Elongation	9·5%	10·25%
Yield stress	37 tons per sq. in.	36·1 tons per sq. in.

Switches and crossings made from that consignment had been laid at various places in the north-eastern area where traffic was heavy, and recent reports indicated that they were giving excellent service, with a prospect of at least double the life of ordinary steel. It was worthy of note that in no case had any flaw or fracture been discovered in the chromium steel switches and crossings already laid down.

The results obtained so far with chromium steel had been such that Mr. Miller had decided to continue the experiments with that steel on a much larger scale, and also to investigate the possibilities of obtaining still better results by treatment after manufacture.

Professor H. C. H. CARPENTER, F.R.S. (Hon. Treasurer), thought the increased resistance to wear described in the paper was very much what one would have expected, having regard to the properties of chromium steel. One point, which was not referred to either in the paper or the discussion, was that the better wear of the rails might be due, not only to their extra mechanical hardness, but also to their extra resistance to corrosion. Looking at the steels constitutionally—which was the way he always preferred to look at them—they consisted of what might be called a chromiferous pearlite and a manganiferous pearlite in a ferrite which probably also contained some chromium and manganese. It was a little difficult to judge of the distribution of the chromium, which was known to improve the resistance of iron to corrosion. He would expect the greater part of it to be present in the pearlite. He did not know whether that was so or not, but he thought the ferrite would contain some chromium at any rate, and that would lead him to expect that the rails were actually more resistant to atmospheric erosion than carbon steel rails of the same carbon content.

He would like some information from the authors on that point if they could supply it.

Mr. J. A. JONES (Research Department, Woolwich), referring to the remark on p. 623 that although the steel was exceptionally hard, the authors did not find it much more difficult to plane than their higher carbon steel, said that in 1921 he had carried out some work on hardened and tempered chromium steels containing up to 3 per cent. of chromium, with about 0.4 per cent. of carbon.¹ Comparative machining tests were carried out on nickel, nickel-chromium, and chromium steels, and it was found that the chromium steels were particularly easy to machine, even at very high tensile strengths.

Dr. H. MOORE, O.B.E. (Research Department, Woolwich), said he was glad to see the authors' views on the use of manganese, which had been confirmed by other speakers, and, in particular, by Mr. Hague. For some time past the Research Department, Woolwich, had been urging that manganese should not be regarded merely as a necessary evil, but that greater attention should be paid to its effect in carbon and other steels, and that it should be regarded, as the authors suggested, as a valuable alloying element. In the range between 1 per cent. and 2 per cent. considerable use of manganese could be made with great advantage in suitable cases.

With regard to the use of chromium, that was also of great interest to his department, which had suggested on several occasions the possible use of chromium steels for structural and engineering purposes, with chromium from 1 per cent. to 3 per cent., according to the purpose in view. The authors' rails contained about 1 per cent. of chromium, and the effect of that had been to increase the tensile strength by about 10 tons per sq. in., with a comparatively small loss of elongation. One of the speakers had referred to the probable effect on the yield point, which in proportion was greater than the effect on the tensile strength; by the use of chromium alone, without nickel or other alloy elements commonly used with chromium, those very important increases in mechanical properties could be obtained at comparatively small cost. If the product were one to which heat treatment could be applied, the advantages were greater still; but even if the material were used in the rolled condition, or after simple normalising, the chromium, in small amounts of that kind and used alone, was capable of conferring a valuable improvement in the properties.

Dr. W. H. HATFIELD (Member of Council) said it must be conceded that manganese was a useful reagent for conferring resistance to wear; the authors had also justified their claims by the data they gave regarding the use of chromium—they had made out their case all round. It would be interesting to be able to visualise how that increased

¹ "The Properties of Some Chromium Steels," *R.D. Report*, No. 51, 1921.

resistance to wear came about, and to ascertain whether it was purely a function of the size and distribution of the carbide particles, or due in a measure to some modification in the characteristics of the matrix, which, presumably, as Professor Carpenter had said, also contained chromium. There were many factors which were not understood at the moment.

Mr. D. SILLARS (Middlesbrough) said there seemed to be a slight misapprehension about the position of manganese in the manufacture of steel rails; it seemed to some extent to be treated as if the use of manganese were objected to. For very many years his firm had been making steels with very much higher manganese than some of the railway companies felt they could venture on, but that was merely due to the undue degree of conservatism displayed by the railways. It was quite common, however, to make rails with up to certainly 1 per cent., and in many cases to a little above 1 per cent., of manganese. With an untreated rail and with one that had to be cooled on the bank, when the manganese reached the neighbourhood of 1.2 to 1.3 per cent., a degree of air-hardening set in which made it extremely difficult to control, except by some delayed cooling treatment after the rail had been rolled.

Mr. Whiteley had referred to a defect which he said appeared in the treatment of rails by the Sandberg process. He remembered reading Mr. Whiteley's paper on that subject, but it had never occurred to him that that paper proved that the gas pressure was the explanation of the presence of the transverse fissures, which gave so much trouble, especially with American rails. He thought it was fairly well known—at any rate it was his own view—that the presence of that spot was due to internal stresses, which were developed no matter how the rail was cooled, and was not due to any more serious inherent defect than might be expected to be present in any well-killed steel of the ordinary kind. He thought it would be extremely surprising if an investigator who took the trouble to cut open the head of a rail should not find something purporting to account adequately for the hypothetical development of some sort of fracture, if the rail were cooled sufficiently rapidly. He had not himself had any experience of chromium steel rails, but one would naturally expect the presence of chromium to have something of the same effect, but in an intensified degree, as manganese. It was possible that the limit of chromium addition might be even lower than that which had been found to be the case with manganese.

Mr. F. W. HARBORD, C.B.E. (Past-President), said there were one or two points to which he wished to refer. Dr. Moore had hinted at the possibility of the desirability of some sort of normalising treatment for chrome steels. His own experience was that all alloy steels were distinctly sensitive to sudden changes of temperature, and he should like to know whether those particular rails, which apparently were put down for experimental purposes, were in any way heat-treated before being put into service.

Taking the case of an ordinary rail bank where the rails were cooling in the open, some slowly and some rapidly, he thought it was necessary to proceed rather cautiously when one got to 1 per cent. of chromium. Some time ago, when testing some rails in which the chromium was just over 0.3 per cent. and the carbon fairly high, the behaviour in the drop test was very far from satisfactory. That might have been an abnormal case, but it was quite a serious matter, because a large quantity had been made, and until they were reheated to about 800° C. and cooled under carefully controlled conditions satisfactory drop tests were not obtained.

On the question of manganese he was rather inclined to agree with the authors that higher manganese in rail steel might be permitted, especially in the case of the lower carbon rails. At present the steel-maker relied upon carbon to give the required physical properties, and if they were to try and obtain them by varying the percentage of manganese within the limits permissible, he was a little doubtful whether they would be able to control the percentage of manganese to the extent necessary to ensure always meeting the requirements of the specification, especially in the case of large heats of basic steel when the manganese had to be added in the ladle. Manganese up to 1.0 or even 1.1 per cent. in the lower carbon rails would probably be quite safe, but with the high-carbon rails the advisability of a manganese content above 0.9 per cent. was, he thought, rather open to question. In the high-carbon rails with manganese 1 per cent. or slightly over, there would be some risk of irregularity due to air-hardening under ordinary conditions of rail manufacture.

CORRESPONDENCE.

Mr. C. P. SANDBERG (London) wrote: Some years ago, at a rail mill in the United States, my firm dealt with very large tonnages of rails, made from Cuban ores, which averaged 0.27 per cent. of chromium and 0.7 per cent. of nickel, with numerous casts with 0.40 to 0.45 per cent. of chromium and 0.70 to 0.80 per cent. of nickel. These elements came through from the ore, and were therefore quite uniform in the steel. The test results were quite satisfactory. The general practice in America in accepting this nickel-chromium analysis was to reduce the carbon by 0.07 per cent. in view of the hardening influence of the nickel and chromium, the carbon content, for instance, being reduced from 0.67 per cent. average to 0.60 per cent. average. Although it was claimed that the nickel and chromium should be advantageous as regards results in the track, I am not aware that the results were such as to justify any special extra price for these rails as compared with the ordinary carbon rails from the same works, but the chromium percentage was, of course, very much lower than that in the rails discussed in this paper.

More recently my firm had experience of a considerable tonnage of chrome steel rails with about 0·7 to 1 per cent. of chromium. While these rails gave results at the works that met the specification, serious trouble was experienced in unloading and laying the rails, some of the rails in question showing great brittleness. It was then found that the chromium content varied very considerably locally, more particularly in one cast. It would seem that great care should be taken to ensure that the chromium addition is thoroughly melted and mixed to avoid such dangerous lack of homogeneity. Irregularity is, of course, very dangerous. The particular rails selected for testing would very likely not show the trouble.

There is no doubt that chromium should give good results as regards wear, and probably also retard corrosion. We shall watch the development of chrome steel for the special purpose of rails with great interest. I would like to add that we entirely concur in Mr. Harbord's remarks.

With regard to the question of higher manganese raised in the paper, I am in great sympathy with this. Very many years ago acid Bessemer rails were rolled containing manganese up to about 1 per cent., and these rails gave very good service. When the open-hearth process was introduced it was found that a clean rolling surface was obtainable with a lower manganese content than the above, and, possibly partly for reasons of cost, the trend in open-hearth steel has been towards considerably lower manganese with a correspondingly higher carbon. Engineers at that time attached considerable importance to higher carbon.

We have dealt with many thousands of tons of tramway rails with a manganese content varying between 1 and 1·4 per cent., which gave excellent results as regards toughness and in service. In America there has been a considerable development recently to reduce the carbon and raise the manganese, and large tonnages have been rolled to this modified analysis, the manganese running well over 1 per cent. We believe the results are encouraging.

On p. 618 there is a reference to a simple heat treatment by air-blasting on a piece of chrome rail. The rate of cooling in the case reported was very much too slow to produce any appreciable change in the structure, or any improvement in the test results. In our sorbitic process the time of duration of the blast, which is much more intense, is from 1 to 2 or 3 minutes, depending on the section, &c., and the resulting rise in tensile test is about 10 tons per sq. in., with a corresponding rise in Brinell hardness of about 50 points. Chrome steel rails would, without doubt, respond at least as well to heat treatment as carbon rails, and we have made some interesting tests in this connection, but until the regularity of chrome steel is more fully proved we would prefer to move extremely carefully.

The extra cost of chrome steel would seem quite trivial in such higher-priced articles as, for instance, railway tyres, where an increased life is equally important. It would therefore be interesting to know

why chrome steel has not been adopted, as far as we know, on any large scale for railway tyres.

Nickel-chrome steel has been largely used for manufacturing gun forgings, but in such steels the carbon content is comparatively low, and, furthermore, such gun forgings are always specially heat-treated.

This paper was presented at the adjourned meeting held in Sheffield on May 10, 1928. The following remarks are extracted from the discussion which took place:

Mr. J. A. JONES (Woolwich) said that the general principle of increasing the manganese rather than the carbon content to obtain enhanced properties was receiving a considerable amount of attention at present in various classes of steel. In the following table, taken from a recent paper,¹ would be found results which showed that for the same maximum load the steel with a high manganese content was distinctly superior to the higher carbon steel.

					High Manganese.	High Carbon.
Carbon.	Per cent.	.	.	.	0.29	0.50
Manganese.	Per cent.	.	.	.	1.60	0.68
Average Brinell hardness number :						
Surface	.	.	.	.	183	186
Middle of thickness	.	.	.	.	188	177
Tensile test :						
Limit of proportionality.	Tons per sq. in.	.	.	.	18.0	13.0
Yield point.	Tons per sq. in.	.	.	.	23.9	21.6
Maximum load.	Tons per sq. in.	.	.	.	41.7	40.9
Yield ratio	.	.	.	.	0.57	0.53
Elongation on 2 in.	Per cent.	.	.	.	31.0	28.0
Reduction of area.	Per cent.	.	.	.	68.0	46.0
Fatigue limit.	Tons per sq. in.	.	.	.	± 20.3	± 17.7
Torsion test :						
Limit of proportionality.	Tons per sq. in.	.	.	.	12.0	11.0
Calculated maximum shear stress.	Tons per sq. in.	.	.	.	39.1	38.9
Twist per unit length.	Degrees.	.	.	.	620	260
Izod notched-bar impact test :						
Notch parallel to surface.	Ft.-lb.	.	.	.	45.0	13.0
Notch perpendicular to surface.	Ft.-lb.	.	.	.	35.0	13.0
Stanton repeated-blow impact test :						
Thousands of blows to } Height of fracture					1.5 in.	1.4
					1.0 "	3.7
					0.5 "	15.8
					0.4 "	24.4
					0.3 "	53.0
					0.2 "	235.5
Sankey bend test :						
Maximum bending effort.	Ft.-lb.	.	.	.	71.0	71.0
Number of bends	.	.	.	.	39	13
Energy absorbed to fracture.	Ft.-lb.	.	.	.	4264.0	1539.0

¹ J. A. Jones, "The Effect of Manganese on the Properties of Low-Carbon Steels," *Metallurgist*, 1927, Oct., Nov., and Dec., pp. 151-154, 166-169, 186-187.

Dr. SWINDEN, in reply, said the authors were very gratified by the interest shown in the discussion. He proposed to refer briefly to a few technical points only, leaving Mr. Johnson to deal with service conditions. In answer to Colonel Belaiew, the authors had originally submitted micrographs of a pair of carbon steel rails, but as they were at 100 diameters only, they were not of any value as far as his point was concerned. There would be no difficulty in providing micrographs at 1000 diameters both of the carbon and chromium steels, treated and untreated.

He was interested in Mr. Whiteley's suggestion of the manganese steel plate down the side of the mould. It was rather analogous to the method for producing the Davis wheel. There would be some practical difficulties, no doubt, but he saw no reason why such an arrangement should not give quite satisfactory results.

He agreed with Mr. Hague that the main factor in limiting the deflection in the drop test was the yield stress, and although the yield point was not given for the Bessemer rails it was given for the open-hearth rails and was of the order of 36 to 38 tons, whereas for the carbon steel rails it would certainly not be more than 28 tons. The reason for the difference in contraction of area between the head and the foot, he imagined, was simply the larger amount of work put on the foot. It was a fairly common experience. Perhaps the particular case quoted was slightly abnormal, and the differences were not generally so great as that, but there was a consistent difference between tests taken from the head and from the foot of the rail.

The authors very much appreciated Mr. Hill's contribution with regard to the experience on the L.N.E.R.

He was much pleased that the general consensus of opinion was in favour of greater latitude in regard to manganese. As stated in the paper, the authors did feel very strongly on the point that the present-day specification, at least as far as home railways were concerned, limited the manganese to 0·8 per cent., which was too low. The specification was 0·55 to 0·65 per cent. carbon, and not over 0·8 per cent. manganese. The manganese limit might very usefully be increased, purely from a service point of view, even if it were thought necessary to reduce the carbon limit—which personally he regarded as doubtful.

Mr. JOHNSON, in reply to an inquiry by the Chairman, said that none of the chromium steel rails put down on the old Midland Railway were heat-treated in any way. They were made in the Bessemer converter. The particular rails described in the paper, rolled by Messrs. S. Fox & Co., Ltd., were taken immediately to the point and crossing works, planed and drilled in the same way as ordinary carbon steel rails, and put in the lines as points and crossings of the 100-lb. Midland Railway standard pattern.

With regard to the reduction of the manganese and the increase of

carbon mentioned in the paper, he had a rather interesting statement to make. From 1900 to 1920—during the time of the old Midland Railway, when he supervised the testing and inspection of the whole of the rails put down—all the rails were made from Bessemer acid steel. There was not a single basic rail of any kind in the lines of the old Midland Company. If the statistics of the Board of Trade during that period were examined, and also those of the Ministry of Transport which afterwards replaced the Board of Trade, it would be found that the Midland Company had the smallest number of breakages of rail of any railway company in the Kingdom. The specification of the particular rails used during that period was as follows :

Carbon	.	.	.	.	.	From 0.40 to 0.50 per cent.
Phosphorus	.	.	.	.	.	Not exceeding 0.07 "
Sulphur	.	.	.	.	.	Not exceeding 0.06 "
Manganese	.	.	.	.	.	1.10 per cent.

The silicon was not mentioned ; it was left to the discretion of the steel-makers to put in what they liked.

Under that specification there was no doubt that very good rails were obtained, and in his personal opinion they compared quite favourably with the open-hearth higher carbon basic rails which were in use at the present moment.

Possibly on account of the exceedingly high rolling-speed and high finishing temperature of steel now usual, one found to-day a certain variation between the head and the foot of modern rails. He was not sufficient of a steel expert to say whether that was definitely due to the modern conditions of rolling, but it was his theory that it was. The point had been mentioned in the discussion. In the days of the old Bessemer rails very little variation was found, and the head would compare roughly with the foot in regard to tensile strength. It did not do that now, and it seemed to him that that might form a special subject of research work by steel experts.

With regard to chromium steel rails, the first trials with such rails were authorised by the chief engineer of the company, who at that time was Mr. Worthington, afterwards President of the Institution of Civil Engineers. The data obtained from exhaustive trials with chromium steel were put before the Main Committee of the Standards Association by Mr. James Briggs, the chief engineer who succeeded Mr. Worthington, and in their report, dated May 1924, the Committee spoke in high terms of the chromium steel rails and recommended further trials.

With regard to the maintenance of the permanent way, everyone knew that points and crossings wore out at a very much quicker rate than ordinary rails laid down at each side, and the authors suggested that the particular steel they described would increase the life of those points and crossings, and as it was not a very expensive steel a considerable saving would result.

At the end of the paper the authors mentioned fishplate steel. There was one point with regard to fishplate steel which he did not think had ever been brought forward, or at any rate he had not seen it. He found that a great many fractures of fishplates occurred in the upper part of the plate, which was rather curious. The upper part of the plate was subject to alternating stresses, and it was found that the fractures occurred on account of a depression which formed in the middle of the plate, due probably to the impinging of the running-on end of the rail. In a certain percentage of plates a hair crack began at the top and gradually extended to the centre, and when half-way the plate broke through. The theory was that owing to a very heavy load between the second and third sleepers, the end of the rail was lifted up, thus bringing the top of the fishplate into tension. As the load came on to the centre of the plate, the top was in compression and the bottom in tension. The steel used for fishplates was softer than that from which the modern rail was made, and therefore the impinging of the rail made the groove in the top of the fishplate. The authors suggested that chromium steel would be more suitable for fishplates, on account of its greater hardness and very much greater elasticity. The steel rails compared with the chromium steel were the acid Bessemer steel rails of which he had just given particulars. He thought the authors were within the mark when they said that the chromium steel would give double the life of ordinary open-hearth basic steel such as was rolled at that particular time. With regard to the 1-in-8 facing crossing mentioned on p. 623, it was actually in the line at the present moment, and up to date had had a life of more than 14 years. That crossing was made to the test B.B. in Table I. on p. 614, and in his opinion that particular analysis had proved the best in service up to the present.

In reply to a question by the Chairman (Mr. Harbord), Mr. Johnson handed in the appended table of analyses of the various consignments of rails supplied to the Midland Railway Company from 1903 to 1911, showing that the manganese was in no case below 1 per cent., and that in 90 per cent. of the cases it ranged from 1·03 to 1·28 per cent. (See next page.)

The authors wrote, in further reply to Mr. Whiteley, that no case of the grey spot or transverse fissures in the chromium steel rails had been met with.

The point raised by Professor Carpenter and Dr. Hatfield concerning the theoretical reason for the increased resistance to wear conferred by chromium would require further laboratory work before a complete reply could be given. It was probable, however, that most of the chromium in the steels in question would be associated with the carbide. Concerning resistance to atmospheric corrosion, a series of laboratory corrosion tests had failed to show any serious difference between the chromium steel and ordinary steel, but the actual results in service did indicate that the chromium steel was more resistant to corrosion, which was important, particularly in the case of rails laid in tunnels.

Replying further to Mr. Harbord, none of the rails in question were subjected to a normalising treatment, and they suggested that the unsatisfactory behaviour of the rails described by Mr. Harbord con-

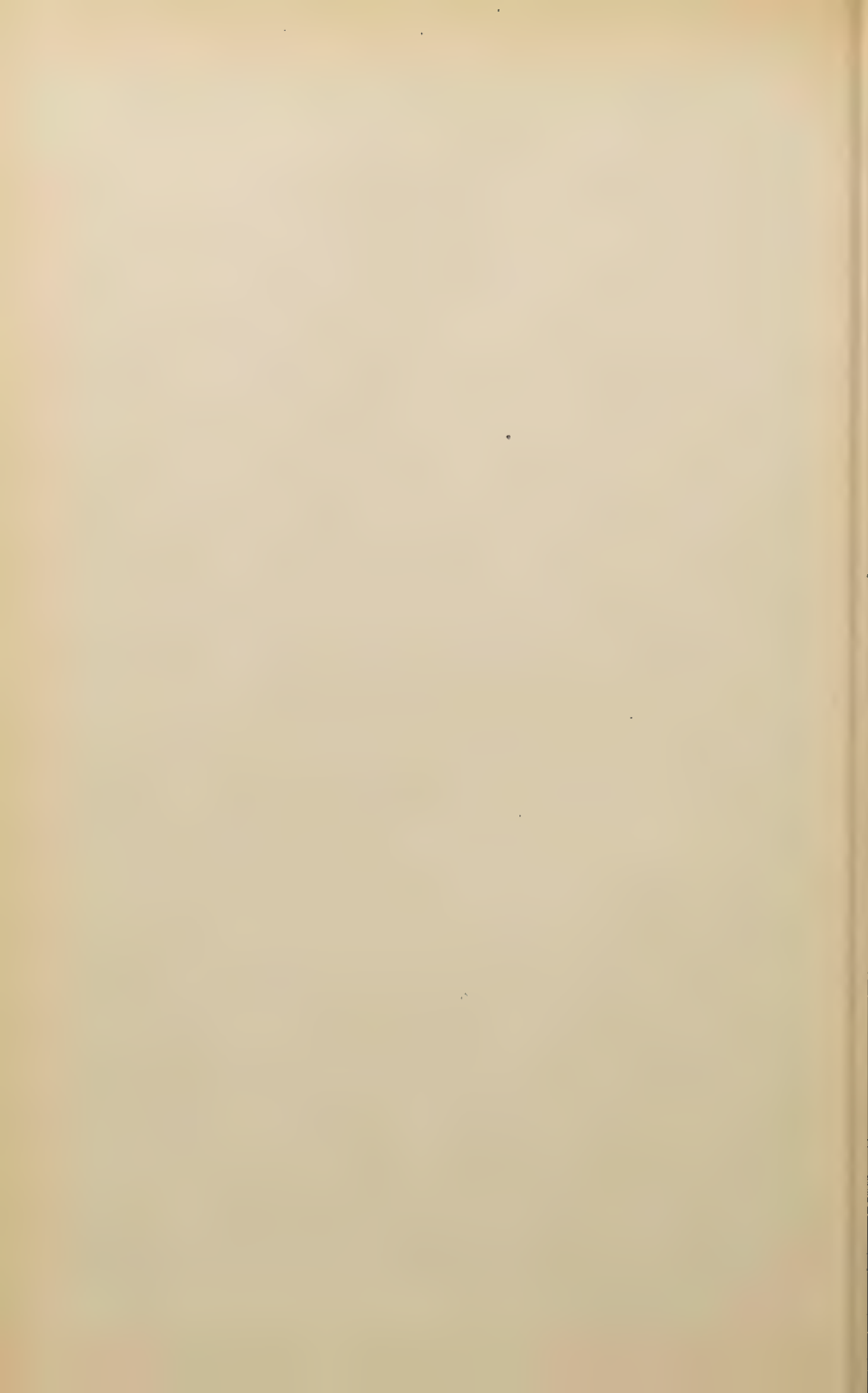
Tests and Analyses of 100-lb. M.R. Rails.

Date and Firm.	Blow.	Ultimate Stress. Tons per sq. in.	Elongation. %	Reduction of Area. %	Carbon. %	Silicon. %	Sulphur. %	Phosphorus. %	Manganese. %	Falling Weight. 3 Blows of 12 ft. on 4 ft. 3 in. Bearings.		
1903. S.F. }	81	49.52	15.5	31.60	0.47	0.065	0.076	0.045	1.16	...	...	...
1904. S.P.T. }	489	42.6	18.0	24.14	0.41	0.052	0.054	0.058	1.05	2.50	4.56	6.50
	132	44.55	19.5	28.44	0.42	0.042	0.055	0.060	1.13	2.25	4.37	6.25
1905. C.L. }	77	47.05	21.5	31.60	0.43	0.068	0.052	0.046	1.22	1.75	3.50	4.75
	69	47.5	17.0	25.40	0.44	0.065	0.053	0.046	1.28	1.87	3.93	4.82
1906. S.P.T. }	522	50.44	18.5	27.36	0.42	0.093	0.054	0.061	1.05	1.87	3.62	5.31
1907. S.P.T. }	676	49.7	17.5	25.20	0.42	0.073	0.065	0.069	1.06	1.75	3.31	5.00
	71	56.5	15.0	20.38	0.50	0.299	0.055	0.064	1.13	1.68	3.12	4.44
1908. S.P.T. }	219	44.82	25.0	30.50	0.42	0.108	0.046	0.062	1.10	2.18	4.31	6.44
	394	49.37	19.5	29.48	0.40	0.065	0.048	0.057	1.11	2.18	4.00	5.90
	45	46.78	22.5	37.60	0.40	0.086	0.052	0.051	1.04	2.18	4.06	6.00
	302	55.8	17.0	25.20	0.48	0.088	0.05	0.061	1.21	1.93	3.62	5.18
1909. S.P.T. }	382	50.62	15.5	21.94	0.44	0.061	0.058	0.051	1.08	2.0	3.68	5.31
	69	53.21	17.5	24.14	0.45	0.109	0.051	0.051	1.03	1.87	3.43	5.00
1909. C.L. }	19	47.67	25.0	39.80	0.50	0.146	0.058	0.042	1.00	1.80	2.87	4.00
1911. C.L. }	194	47.32	20.0	33.80	0.47	0.064	0.043	0.052	1.00	1.90	3.50	5.00
	385	52.32	17.0	29.60	0.48	0.132	0.049	0.051	1.01	2.00	3.70	5.20
1911. S.F. }	361	47.00	19.0	31.60	0.45	0.06	0.046	0.043	1.05	2.00	3.50	5.80
	5	46.9	16.3	27.40	0.40	0.071	0.044	0.056	1.05	1.90	3.50	5.10
	183	52.2	11.6	18.60	0.54	0.049	0.056	0.047	1.06	1.70	3.20	4.60

taining about 0.3 per cent. chromium was due to factors other than the chromium content *per se*.

The authors were extremely indebted to Mr. C. P. Sandberg for his interesting contribution. The simple heat treatment referred to on p. 618 was not intended to reproduce the sorbitising process, and they were gratified to note that, in the opinion of Mr. Sandberg, chromium steel rails would without doubt respond at least as well to heat treatment as carbon rails. Concerning the unsatisfactory behaviour of some chromium steel rails which came within the experience of Messrs. Sandberg, the authors could only conclude that such material was improperly made, and that experience should not be allowed to impede the development of what the authors considered to be a perfectly reliable material if proper care were taken in its manufacture.

The authors very much appreciated the contributions by Mr. Jones and Dr. Moore, and they noted with interest Mr. Sillars' opinion concerning manganese.



A STUDY OF THE RESISTANCE OF OVER-STRESSED WROUGHT IRONS AND CARBON STEELS TO SALT-WATER CORROSION.¹

BY J. NEWTON FRIEND (BIRMINGHAM).

It has now been well established that over-strained iron and steel are attacked more rapidly in acid media than the unstrained, annealed metals.² The results of laboratory tests on stretched irons and carbon steels in neutral media, however, have not pointed so clearly in the same direction, for sometimes the stretched metals proved a little more corrodible than the annealed specimens, and sometimes the reverse was the case.³ Usually there was but little to choose between the two, and the mean results practically coincided. Experiments with compressed and twisted specimens do not appear to have been carried out quantitatively hitherto.

The foregoing results under neutral conditions are somewhat difficult to understand. The general opinion appears to be that the resistance of ferrous metals to corrosion is materially weakened by stretching. If this is the case, it is clear that the laboratory tests have failed in some way to conform to practice. On the other hand, it is known that the surface layers of worked brasses are more resistant to sea-water corrosion than the annealed metal,⁴ and it appeared possible that ferrous metals might behave in a similar manner.

On comparing the conditions under which the above-mentioned

¹ Received January 2, 1928.

² See Heyn and Bauer, *Journal of the Iron and Steel Institute*, 1909, No. II. p. 109. The medium employed was dilute sulphuric acid. Also Friend, *Iron and Steel Institute : Carnegie Scholarship Memoirs*, 1922, vol. xi. p. 103.

³ Friend, *loc. cit.* Also "The Deterioration of Structures in Sea-Water," *Institution of Civil Engineers. Fourth Interim Report*, 1924, p. 40; *Third Interim Report*, 1923, p. 58.

⁴ Gibbs, Smith, and Bengough, *Journal of the Institute of Metals*, 1916, No. 1, p. 48. Bengough, Jones, and Pirret, *ibid.*, 1920, No. 1, p. 65. Bengough and May, *ibid.*, 1924, No. 2, p. 192.

laboratory tests were carried out with those usually obtaining in practice, several points suggested themselves as worthy of investigation. The present research deals with some of these.

1. *Duration of the Tests.*—The extreme limits of the laboratory tests have hitherto been one year. In practice, steel structures are expected to have a working life of many years, and it may reasonably be urged that even if within any single year the strained and unstrained metals show but little difference, yet the cumulative effect of the strain in the course of several years may be serious.

In Series I., therefore, the tests have been prolonged for a period of three years, and in Series II., IV., V., and VI. the specimens have been exposed, for two successive periods of one year each, to the action of salt water.

2. *Regularity of Strain.*—In previous tests the specimens had been strained fairly uniformly throughout their small bulk, and during the period of the tests they were isolated from each other, resting on blocks of wax or other insulating material, so that electrochemical action between the various pieces was impossible. In practice these conditions can hardly occur. Strained portions of metal will normally lie in contact with less severely strained or unstrained metal, and at these junctions electrochemical action might reasonably be expected to occur, resulting in localised corrosion.

In Series II., III., V., and VI. are given the results of exposing bars, which have been stressed unequally throughout their lengths, to the action of salt water.

3. *Surface Conditions.*—When iron and steel are overstrained, fine cracks, visible even to the unaided eye, frequently appear on the surface. These may serve as starting-points for corrosion. In the laboratory tests these have been largely removed during the subsequent process of machining to size. In Series III., therefore, the stretched bars have been exposed to corrosion in salt water in their "natural" state, just as they left the tensile machine, save that their ends were trimmed.

4. *Nature of the Overstrain.*—Hitherto quantitative laboratory tests have been confined to stretched bars. In Series IV., V., and VI. the effects of compression and torsion have been studied.

Materials Used in Laboratory Tests.

The metals used in this research were obtained as round bars, the chemical compositions and mechanical properties of which

TABLE I.—*Chemical Analyses and Mechanical Properties.*

Identity Mark.	Material.	Chemical Analysis.						Yield Point. Tons per sq. in.	Ultimate Stress. Tons per sq. in.	Elongation. %	Reduction of Area. %	Ball Hardness Number.
		Carbon. %	Silicon. %	Sulphur. %	Phosphorus. %	Manganese. %	Copper. %					
AA BB CC DD	Carbon steels	0.174 0.467 0.920 1.350	0.132 0.150 0.076 0.092	0.033 0.051 0.024 0.024	0.033 0.044 0.030 0.027	0.600 0.480 0.706 0.286	ND ND ND ND	26.9 28.4 35.4 33.2	34.4 44.7 65.1 57.6	27.7 14.8 9.0 1.6	............	............
HBBB L	Wrought irons	0.036 0.034	0.10 0.11	0.038 0.017	0.21 0.14	0.13 0.03	0.08 0.04	18.16 18.12	23.62 23.94	33.00 28.30	47.2 50.0	112 107
AM RS HI DV H2 RM WH	Carbon steels	0.025 0.05 0.11 0.116 0.14 0.20 0.32	0.15 0.005 0.004 0.028 0.016 0.005 0.132	0.014 0.043 0.033 0.081 0.052 0.055 0.046	0.031 0.122 0.058 0.048 0.073 0.061 0.055	0.05 0.41 0.33 0.455 0.35 0.69 0.64	0.01 0.03 0.01 ND 0.02 0.04 ND	19.68 20.32 17.71 15.44 18.64 19.69 22.35	25.06 27.26 25.35 20.48 28.06 30.66 38.66	28.90 34.20 32.20 36.00 26.10 28.00 23.30	43.2 68.2 65.4 72.8 54.2 59.8 52.0	126 103 92 105 107 118 153

ND = not determined.

are given in Table I. The dimensions of the bars used in obtaining the mechanical data were as follows :

(a) Bars AA, BB, CC, and DD were 1 in. in diameter. Test-bars were cut from each and machined to the shape shown in

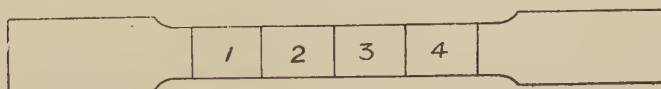


FIG. 1.—Test-Bar used in Series I.

Fig. 1. They were 9 in. long, the central machined portion measuring approximately 5 in. in length and 0.750 in. in diameter. They were marked off at points exactly 1 in. apart, stretched to rupture, and the total sectional elongations noted.¹

(b) The remaining bars were 1½ in. in diameter, and test-bars

¹ Later, these bars were sawn at the sectional marks into small cylinders and exposed to corrosion (Series I.).

were prepared from them of similar general shape to the preceding, but 13 in. in over-all length, the narrower middle part measuring 8 in. in length and 0.745 in. in diameter. After rupture one of the broken "halves" of each bar was used in the tests summarised in Series III.

Method of Experiment.

The various specimens, prepared as described below, were measured and weighed and placed on wax blocks in a large corrosion tank containing nearly 1 ton of salt water.¹ After exposures of from 1 to 3 years the specimens were removed, cleaned, and weighed, the loss in weight being taken as a measure of the corrosion.

I. THE EFFECT OF TENSILE STRESS ON CORRODIBILITY.

Series I.—Tests with Small Cylinders of Stretched Steel Machined to Uniform Size.

In this series, specimens were prepared from test-bars AA, BB, CC, and DD.² After rupture and measurement of the sectional elongations the lower of the two pieces from each broken test-piece was turned to uniform diameter and sawn at the marked sections into small cylindrical pieces, approximately 0.8 in. in height and 0.6 in. in diameter. The exact size of each piece was measured and the area exposed to corrosion calculated. It was assumed that the portions of the metal under the grips during stretching were not appreciably strained, and similar cylinders were machined from these to serve as standards.

The specimens were completely immersed in salt water for three years, after which their losses in weight were determined.³ The results are given in Table II.

As usual, when testing a considerable number of specimens of steel, certain irregularities occurred. Thus specimens AA2 and BB4 lost appreciably more in weight than the corresponding

¹ Made by dissolving the requisite quantity of crude rock-salt in the water to resemble sea-water.

² They were portions of the same steel bars used in the author's previous tests mentioned on p. 639.

³ The author desires to acknowledge the kind assistance of Mr. Walter West in preparing these specimens and arranging the tests.

unstretched standards AA0 and BB0 respectively. The majority of the remaining stretched specimens, on the other hand, lost

TABLE II., *Series I.—Corrosion of Stretched Steel Cylinders after Continuous Immersion in Salt Water for Three Years, 1924–27.*

Identity Mark.	Carbon. %	Elongation. %	Original Weight. Grm.	Loss in Weight. Grm.	Relative Corrosion for Equal Areas.
AA 0	0.174	0.0	28.464	0.290	100
2		17.2	27.252	0.358	128
3		34.4	27.739	0.302	106
BB 0	0.467	0.0	26.259	0.230	100
2		9.4	30.136	0.260	102
3		10.9	27.345	0.225	94
4		29.7	29.938	0.294	116
CC 0	0.920	0.0	31.378	0.283	100
3		9.4	28.219	0.252	97
DD 0	1.350	0.0	32.303	0.281	100
4		1.6	30.888	0.254	94

slightly less in weight than their corresponding standards. Taking the mean of all the data, the ratio was as follows :

Relative corrosion of unstretched metals	.	.	.	100
Relative corrosion of stretched metals	.	.	.	105

The effect of the stretching has not been to influence seriously the corrodibilities of the metals.

Series II.—Tests with Unequally Stretched Bars Machined to Uniform Size.

Five test-bars of wrought iron, HBBB, and five of mild steel, H2, were cut and turned to the dimensions given in Fig. 2.

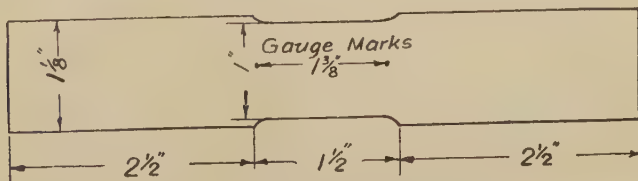


FIG. 2.—Test-Bar used in Series II.

They were then stretched by varying amounts, but not to rupture, and were finally cut and machined to a common standard—namely, 0.900 in. in diameter and 6.0 in. in length. The specimens thus obtained, although uniform in appearance, were unequally strained throughout their lengths, the greatest over-strain occurring about their middle. The specimens were laid horizontally in the corrosion tank, their ends resting on blocks of wax.¹ After exposure for one year they were removed, examined, and their losses in weight determined. They were then replaced for a second year in the tank, and afterwards again examined. The results are summarised in Table III. :

TABLE III., *Series II.*—*Corrosion of Stretched Bars after Continuous Immersion in Salt Water for Two Years, 1925-27.*

Diameter of each bar . 0.900 in.

Length of each bar . 6.00 in.

Identity Mark.	Metal.	Carbon. %	Elongation between Gauge Marks. In.	Load required. Tons.	Original Weight. Grm.	Loss after One Year, 1925-26. Grm.	Loss after Second Year, 1926-27. Grm.	Total Loss. Grm.	Mean Relative Corrosion for Two Years, 1925-27.
HBBB 1	Wrought iron	0.036	Nil	Nil	455.40	2.14	2.40	4.54	100
2			Nil	Nil	455.45	2.17	2.36	4.53	100
3			$\frac{1}{8}$	14.8	454.48	2.01	2.41	4.42	97
4			$\frac{1}{8}$	16.5	455.64	2.13	2.38	4.51	99
5			$\frac{1}{8}$	17.7	453.78	2.14	2.41	4.55	100
H2 1	Mild steel	0.14	Nil	Nil	462.38	2.03	2.54	4.57	100
2			Nil	Nil	464.50	2.05	2.50	4.55	100
3			$\frac{1}{8}$	16.0	467.20	2.17	2.37	4.54	100
4			$\frac{1}{8}$	19.5	463.22	2.07	2.46	4.53	99
5			$\frac{1}{8}$	20.7	460.95	2.22	2.40	4.62	101

The metal surfaces were somewhat irregularly attacked, but there was no pitting as ordinarily understood. There was no appreciable difference between the stretched and unstretched specimens either in appearance or loss in weight.

Series III.—*Tests with Stretched Bars in their "Natural" Condition.*

The longer portions of seven of the test-bars listed in Table I. were taken, the threaded heads which had been in the grips were sawn off and the rough, ruptured ends ground flat. The remainder of the surface was left untouched in its "natural" condition with any surface cracks or defects caused by the stretching. Pieces of unstretched metal from the corresponding stocks of bars were

¹ The salt water had thus free access to all parts of the bars except for a fraction of their under sides at the extreme ends.

then cut and machined as closely as possible to the sizes of the stretched specimens to serve as standards of comparison. After measuring and weighing, the specimens were immersed in the salt-water tank for one year. They lay horizontally, their ends being supported on blocks of wax.

Upon removal the bars were seen to have been fairly uniformly attacked. There was no pitting. In almost every case (see Table IV.) the stretched bars lost less in weight than the un-

TABLE IV., *Series III.—Corrosion of Stretched Bars in their "Natural" Condition after Continuous Immersion in Salt Water for One Year, 1926-27.*

Identity Mark.	Metal.	Carbon. %	Condition of Bar.	Length. In.	Initial Weight. Grm.	Loss in Weight. Grm.	Relative Corrosion.
L HBBB	Wrought irons	0.034 {	Normal	7.1 {	369.39	1.89	100
			Stretched			358.86	1.84	97.4
		0.036 {	Normal	6.8 {	336.52	1.59	100
			Stretched			325.01	1.54	96.9
AM	Carbon steels	0.025 {	Normal	7.6 {	401.45	1.98	100
			Stretched			386.30	1.87	94.4
RS		0.05 {	Normal	5.4 {	273.26	1.53	100
			Stretched			264.20	1.34	87.6
DV		0.116 {	Normal	6.7 {	328.26	1.81	100
			Stretched			320.21	1.44	79.6
H2		0.14 {	Normal	5.9 {	312.77	1.56	100
			Stretched			306.36	1.54	98.7
WH		0.32 {	Normal	6.4 {	346.41	1.85	100
			Stretched			339.40	1.92	103.8

stretched, the one exception being the 0.32 per cent. carbon steel, WH, the stretched specimen losing 3.8 per cent. more. In one case, steel DV, the difference was very pronounced, the stretched bar losing 20.4 per cent. less than the normal bar.

II. THE EFFECT OF COMPRESSION ON CORRODIBILITY.

As no quantitative tests on the influence of compression on corrodibility appear to have been carried out, it was thought desirable to arrange two sets of experiments, namely:

(a) With small discs uniformly compressed.

(b) With bars compressed unequally throughout their lengths.

The preparation of these specimens required very considerable

manipulation, and the author desires to express his appreciation of the assistance rendered by Sir Robert Hadfield and his staff in this connection.

Series IV.—Tests with Small Discs of Compressed Metal.

For these experiments bars L, HI, and RM were selected. They were annealed by heating to 900° C. and slowly cooling in the furnace to bring them to an exactly comparable condition. Preliminary tests showed that at 34 per cent. compression a crack started in the wrought iron L, and at 40 per cent. compression the crack was wide open ; so with this metal the range of compression was limited to 30 per cent. Steel HI (0.11 per cent. carbon) commenced to crack at 60 per cent. compression. It was therefore decided to limit the range of compression of both steels to a maximum of 50 per cent. Eighteen specimens were prepared, six with each kind of metal, and the extents of compression were so arranged as to give as many direct comparisons as possible. After compression the specimens were machined to a common diameter of 0.798 in. and cut to a length of 0.44 in. After weighing they were laid on a waxed glass plate and immersed in the salt water corrosion tank for two successive years, the losses in weight after each year being determined. Details are given in Table V.

Results with Wrought Iron, L.—In four out of five cases the compressed specimens lost less in weight than the annealed standard. The greatest loss in weight was suffered by L6, which had also undergone the greatest compression, but even in this case there was only 1 per cent. difference between the compressed metal and the standard. The mean result was as follows :

	Relative Corrosion.
Annealed specimen L1	100
Mean of compressed specimens L2 to L6	91.1

Results with 0.11 per cent. Carbon Steel, HI.—On the whole there was little to choose between the annealed and compressed specimens, the mean result being :

	Relative Corrosion.
Annealed specimen HI7	100
Mean of compressed specimens HI8 to HI12	100.9

Results with 0.20 per cent. Carbon Steel, R.M.—The compressed specimens suffered slightly, but unmistakably, more corrosion than the annealed, the mean result being:

Annealed specimen RM13	Relative Corrosion.	100
Mean of compressed specimens RM14 to RM18		110.9

It is well known that cold-working in general tends to reduce the density of iron. This is well illustrated in the case of the wrought iron specimens, the densities of which are given in Table V.

TABLE V., *Series IV.*—*Corrosion of Compressed Discs Exposed to Continuous Immersion in Salt Water for Two Successive Years, 1925-27.*

Diameter of each disc . 0.798 in. Length of each disc . 0.44 in.

Identity Mark.	Metal.	Carbon. %	Length before Compression. In.	Length after Compression. In.	Pressure required. Tons.	Compression. %	Density at 18.5° C.	Original Weight. Grm.	Loss after One Year, 1925-26. Grm.	Loss after Second Year, 1926-27. Grm.	Total Loss in Two Years. Grm.	Mean Relative Corrosion for Two Years.
L 1	Wrought iron	0.034	0.440	0.440	0	0	7.7256	27.8862	0.1126	0.2208	0.3334	100.0
2			0.505	0.5	10.5	1	7.7212	27.7434	0.1014	0.1892	0.2906	87.2
3			0.525	0.5	25.0	5	7.7220	27.7108	0.0886	0.1888	0.2774	83.2
4			0.560	0.5	32.0	10	7.7053	27.7294	0.1026	0.2244	0.3270	98.1
5			0.625	0.5	41.0	20	7.6897	27.6355	0.1102	0.1765	0.2867	86.0
6			0.720	0.5	60.0	30	7.6566	27.5220	0.0980	0.2388	0.3368	101.0
HI 7	Steel	0.11	0.440	0.440	0	0	...	28.3254	0.1050	0.2520	0.3570	100.0
8			0.505	0.5	10.0	1	...	28.4236	0.1148	0.2318	0.3466	97.1
9			0.560	0.5	29.5	10	...	28.4110	0.1270	0.2488	0.3758	105.3
10			0.625	0.5	39.0	20	...	28.2848	0.1206	0.2310	0.3516	98.5
11			0.720	0.5	50.0	30	...	28.3134	0.1142	0.2460	0.3602	100.9
12			1.00	0.5	80.0	50	...	28.3340	0.1270	0.2396	0.3666	102.7
RM 13	Steel	0.20	0.440	0.440	0	0	...	28.3104	0.1104	0.2240	0.3344	100.0
14			0.505	0.5	14.0	1	...	28.2804	0.1310	0.2246	0.3556	106.3
15			0.560	0.5	39.0	10	...	28.3050	0.1282	0.2466	0.3748	112.1
16			0.625	0.5	57.0	20	...	28.2586	0.1318	0.2552	0.3870	115.7
17			0.720	0.5	66.0	30	...	28.2577	0.1060	0.2347	0.3407	101.9
18			1.00	0.5	95.0	50	...	28.2560	0.1350	0.2610	0.3960	118.4

Series V.—*Tests with Compressed Bars Machined to Uniform Size.*

The same metals were selected for this series as for the previous. After annealing, a test-bar of each was prepared of the dimensions shown in Fig. 3. It was turned to a diameter of $\frac{1.5}{16}$ in., with a portion in the middle 1.74 in. long and 1 in. in diameter. This central portion was tapered into the smaller diameter for a distance

of $\frac{1}{4}$ in. on either side, after which it was cold-hammered in swages until the whole bar was of uniform diameter, namely, $\frac{1}{16}$ in., care being taken that the hammer did not touch the bar outside the limits of the taper portion. The bar was then turned and finished to a smooth diameter of 0.930 in., the ends cut off and faced to

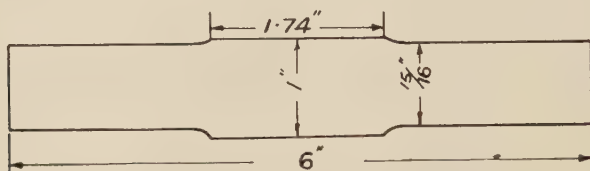


FIG. 3.—Test-Bar used in Series V.

a length of 5.63 in., with the cold-worked portion in the middle. After weighing, the bars were supported horizontally for two successive years in the salt-water corrosion tank, their ends resting on wax blocks exactly as in Series II. The losses in weight are given in Table VI.

TABLE VI., Series V. and VI.—Corrosion of Compressed and Twisted Bars Exposed to Continuous Immersion in Salt Water for Two Successive Years, 1925-27.

Identity Mark.	Metal.	Carbon. %	Condition.	Original Weight. Grm.	Loss after One Year, 1925-26. Grm.	Loss after Second Year, 1926-27. Grm.	Total Loss in Two Years. Grm.	Mean Relative Corrosion for Two Years.
L	Wrought iron	0.034	Annealed	485.05	1.33	2.21	3.54	100
			Centre compressed	481.87	1.23	2.14	3.37	95
			Twisted	485.70	1.16	2.31	3.47	98
HI	Steel	0.11	Annealed	492.98	1.60	2.14	3.74	100
			Centre compressed	490.16	1.23	2.25	3.48	93
			Twisted	492.02	1.32	2.27	3.59	96
RM	Steel	0.20	Annealed	491.15	0.71	2.50	3.21	100
			Centre compressed	489.04	1.02	2.46	3.48	108
			Twisted	491.60	1.57	2.29	3.86	120

The bars were fairly evenly attacked, the compressed specimens showing a slight tendency to pit in their centres. The wrought iron corroded in such a manner as to reveal its fibrous structure. Only in the case of the 0.20 per cent. carbon steel was compression accompanied by increased corrosion.

III. THE EFFECT OF TORSION ON CORRODIBILITY.

Series VI.—Tests with Twisted Bars Machined to Uniform Size.

The same metals were selected for this series as for the two previous. After annealing, a test-bar of each was prepared of the dimensions shown in Fig. 4. It was then held firmly in dies at each end and twisted through 45° . It was next turned to a uniform diameter of 0.930 in. by turning off sufficient, but only just sufficient, material to restore the centre portion of each

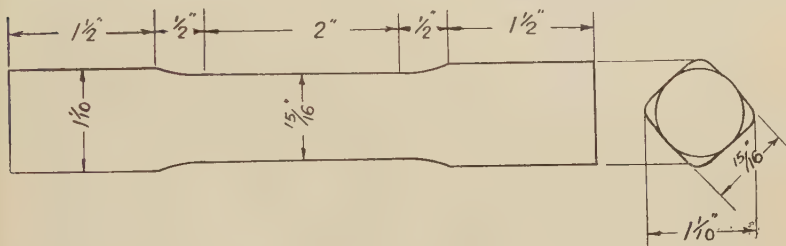


FIG. 4.—Test-Bar used in Series VI.

bar to a truly cylindrical shape. After weighing, the bars were exposed to the action of salt water for two successive years in exactly the same manner as in Series V. The results are summarised in Table VI.

The bars were fairly evenly attacked, the fibrous structure of the wrought irons being revealed. Only in the case of the 0.20 per cent. carbon steel did the twisted specimen lose more in weight than the annealed.

SUMMARY OF THE RESULTS.

1. *Wrought Iron*.—The corrodibility of the metal in salt water is not enhanced by stretching even to rupture, by twisting, or by compression up to 30 per cent.

2. *Carbon Steel*.—(a) The corrodibility of carbon steels (0.025 to 1.35 per cent. carbon) in salt water does not appear to be enhanced by stretching even to rupture. (b) Torsion and compression within the range described in this paper do not appear to affect appreciably the rate of corrosion of 0.11 per cent. carbon

steel in salt water. (c) Torsion and compression increase slightly the corrodibility of 0.20 per cent. carbon steel in salt water.

CONCLUSION.

In considering these results it is important to bear in mind their limitations. They do not necessarily apply to alternate wet and dry conditions, or to the action of fresh water; further, they are merely results of laboratory tests, the specimens being at rest throughout the periods of exposure. *Every care must be taken, therefore, in view of the immense importance of the subject, not to read into the results more than they will legitimately bear.*

On the other hand, the author has recently shown¹ in an extensive series of laboratory and "field" tests carried out synchronously that if laboratory tests are carried out under conditions approximating to field practice the results may reasonably be expected to give a clear indication of the manner in which the metals will behave in practice.

As a general conclusion, therefore, it would appear that neither wrought iron nor steel up to 0.11 per cent. carbon is rendered more corrodible in salt water by stretching, even to rupture, by torsion through 45° or by compression, provided the last named does not lead to cracking. In the case of 0.20 per cent. carbon steel, twisting through 45° and compression appear to enhance corrosion slightly.

These results refer to iron and steel at rest. It frequently happens in practice that the metals are subjected to alternating stresses, as in pier piles, &c.² These alternating stresses may lead to cracks and structural failure, the effect being enhanced by the penetration of salt water into the cracks, thus accelerating disruption. Such increased corrosion is, however, really a secondary effect due to cracking rather than a primary effect of stress *per se*. For this reason, therefore, strains should always be avoided whenever possible in practice.

¹ Friend, *Iron and Steel Institute : Carnegie Scholarship Memoirs*, 1927, vol. xvi. p. 131.

² See McKaig and Friend, *Fourth Interim Report*, *loc. cit.*

DISCUSSION.

Dr. G. D. BENGOUGH (London) said the paper raised in an acute form the question of what methods for measuring corrosion should be adopted in laboratory researches, and what relations there should be between different laboratory investigations and also between laboratory investigations and measurements made under industrial conditions.

The conclusion reached by the author was that stresses and strains of various kinds did not appreciably influence the rate of corrosion of the metals investigated; that might be quite correct, but personally he did not think it was proved by the measurements quoted. He thought that the conclusion reached in the paper was not of a general order, but would apply only to the particular experimental conditions which the author had used. The author purported to compare the corrodibilities of certain types of iron and steel. He treated corrodibility as if it were definitely a property of the metals themselves, like specific gravity and conductivity, which only varied slightly under experimental conditions; whereas actually corrodibility depended on a great number of other factors, many of which were quite independent of the metal itself. About those factors the author said almost nothing with regard to his experimental conditions.

What really ought to be done, he thought, in corrosion work was to gather together quantitative data obtained under perfectly definite and known conditions. It would be a long process, but in time it would be possible to map out a large plan of precisely defined facts. Then, if it were desired to know at what rate definite metals would corrode under particular conditions, or if the practical conditions to which the metals were to be exposed were known, it would be possible to get the data required from that large body of experimental results. Unless corrosion experiments were carried out under definite conditions, however, it was not possible even to start to accumulate the required data.

He thought the most serious omission from the paper was the lack of data with regard to oxygen supply. The author did not say anything about the depth to which his specimens were immersed, nor did he say how close they were together. That was of great significance, because if the oxygen supply was a salient factor in determining the rate of corrosion—and he thought it was—the distance between the specimens was a very important matter. If they were too close they would interfere with each other's oxygen supply.

Another point in connection with oxygen supply was that in the course of the experiments it would probably fall off as time went on; if it did so, a straight line course would not be obtained for the corrosion rate. As long as the oxygen supply was kept fairly constant a straight

line curve representing a definite corrosion rate would be obtained; but as time went on and rust accumulated on the surface of the specimen the rate of oxygen supply might be diminished and one would get a different curve. The slope would be determined by the original oxygen supply as long as the total corrosion was not very great, and it would fall off as corrosion products were accumulated. If that were so, the real determining factor in these experiments was the rate of oxygen supply.

He did not think for a moment that the slopes of the corrosion curves in Dr. Friend's experiments were determined by the metals. If the rate of corrosion was really determined by the oxygen supply it would not be possible to distinguish between the different materials which corroded at fairly equal rates. It would be possible to separate out one metal only, provided it corroded considerably less than the others; a nickel steel was such an alloy, because it could not take advantage of the whole of the oxygen supply given it, but if all those metals really did corrode in nearly the same way and sufficiently rapidly to use all the oxygen supply, it would be impossible to discriminate between them. That was a very important general point in regard to corrosion, and all research must take account of that if it were to be generally useful. One might be hiding very considerable differences between metals, unless one gave fairly full details about the rate of oxygen supply that was given to the metals.

There were one or two very interesting points about the paper on which it was surprising to find the author did not comment at all, and on which he would like more information. In Table III. the author had got a surprisingly close agreement between his different results; of the ten results nine agreed to within 1 per cent. That was a closer agreement than could be obtained even in the most refined experimental work on corrosion, and it was much better than occurred in other tables in the paper. In ordinary corrosion tests one expected to get differences in corrosion rates between different experiments of something like 10 to 12 per cent., and such discrepancies occurred in the other tables; he wished to ask the author for an explanation of the close agreement shown in Table III. He suggested it was partly due to the way in which those specimens were suspended in the thermostat. They were 6-in. specimens, suspended horizontally clear of the bottom of the thermostat; if the results given in that table were carefully calculated out, it would be found that those specimens were corroded very much faster than specimens given in some of the other tables, such as Table V. Those given in Table V. were small specimens which stood on the bottom of the thermostat on wax. The big ones corroded 50 per cent. more rapidly than the small ones. The reason seemed to be that the small ones were covered by a thick blanket of rust, whereas with the rounded bars part of the blanket fell off and allowed a faster rate of oxygen supply to the metal itself. It was remarkable that those large specimens, suspended above and away from the bottom of the thermostat, corroded

50 per cent. more rapidly than the small ones. The fact that a great deal of the rust deposits fell to the bottom of the thermostat and that the bars were 6 in. long might account for the fact that the results were so much closer together than the others.

Another rather remarkable conclusion which surprised him was that the twisted steel was the only one that corroded more rapidly than the annealed metal. The author based that on the specimen for annealed metal, which lost 0.71 gm. after one year. That was quite an abnormal figure, and the author was therefore comparing his twisted and compressed figures with that abnormal specimen which was corroding very much less than any of the others in the tables. Why that particular specimen corroded so slowly he did not know, but it should not be used to give a comparison for the twisted and compressed specimens in that table.

Mr. U. R. EVANS (Cambridge) said an explanation might be suggested for the fact that, although acids attacked strained iron more rapidly than unstrained, in neutral liquids under the conditions studied, strain had very little effect on the corrosion of iron. Acids could attack iron readily, even in the absence of oxygen, yielding soluble salts; any traces of insoluble products (rust) formed by hydrolysis were usually produced far away from the surface, and generally in a diffuse form which did not seriously interfere with diffusion. On the other hand, neutral liquids only corroded iron rapidly in the presence of oxygen, and they produced insoluble compounds (rust) close to the metallic surface; if the whole surface became blanketed with rust, the corrosion would be slowed down, being controlled by the rate at which oxygen could diffuse through the rust layer to the metal; and since there was no reason why it should diffuse more quickly towards strained iron than towards unstrained, the two materials would, under those conditions, be eaten away at approximately the same rate, except in the initial period before the rust blanket had developed sufficiently to control the rate of attack. Some values quoted by Chappell¹ illustrated that fact aptly; they showed that in a 3-day test steel was corroded distinctly more quickly than pure iron, but in a 2½-year test both materials gave almost identical corrosion figures, the velocity of attack being controlled by the rate of diffusion of oxygen through the thick blankets of rust.

Since at first sight that might appear to conflict with the well-known idea that "rust promotes further rusting," that idea must be examined a little more closely. According to the view of rusting now held almost universally by those who were working on the subject—a view to which, he believed, Dr. Friend himself subscribed—rust was not a direct oxidation product of iron, but was a precipitate formed by a secondary action. When iron was immersed in salt water, electric currents passed between different parts of the surface, usually generated by differences in oxygen concentration in the liquid (although sometimes they might

¹ *Industrial and Engineering Chemistry*, 1927, vol. xix. p. 464.

be set up by physical or chemical differences between different parts of the metal). The currents would only flow if oxygen were supplied to the cathodic portions, but as long as oxygen was supplied there, corrosion would occur at the anodic portions. The immediate products would be soluble bodies—namely, ferrous chloride at the anodic portions and sodium hydroxide at the cathodic portions; it was only where those soluble bodies met and interacted, usually in the presence of a further supply of dissolved oxygen, that the mixture of insoluble iron hydroxides called rust was obtained. If flocculent, porous rust accumulated on one portion of the surface only, it would screen that portion from oxygen, thus rendering it susceptible to anodic corrosion, provided that there was some other portion, not blanketed with rust, which could receive oxygen and function as cathode; in that sense, rust promoted the rusting of the metal on which it rested. But if the whole surface became blanketed with rust, there was no area available to act as cathode, and corrosion must cease; in that case, therefore, rust stifled rusting. The degree to which rust prevented diffusion of oxygen depended on its physical character, and Dr. Friend had done good service in calling attention to the importance of colloid-chemical influences.

Of course, if Dr. Friend were able to assure them that all his specimens retained important rust-free areas throughout the period of the test, it would be agreed that the experiments proved that strain did not affect the total corrosion. But even that did not show that strain was not dangerous. It seemed undeniable that in some cases local strain was very dangerous, because it concentrated on the intensely strained portion an attack which would otherwise be spread out over the whole surface. In one case which he recently examined, a piece of steel had been punched with an identification mark and immersed in salt water; the corrosion had produced complete perforation all along the outline of the punch mark, although elsewhere there was only mild general attack. There was no reason to think that the total corrosion was abnormally high; the effect of the strain was simply to localise upon a small area the attack which would otherwise have been harmlessly spread out.

Strain might produce dangerous localisation of attack in three different ways:

- (1) The potential of the highly strained area being probably different from that of the less strained area, the former was liable to suffer anodic attack.

- (2) The strain might produce incipient cracks, the interiors of which—being less accessible to dissolved oxygen—might suffer anodic corrosion through the differential aeration effect.

- (3) The strain might keep cracking protective oxide films produced by direct oxidation by the air.

The case of perforation described above was probably due to the first cause. The second was definitely excluded, since the portions adjacent to the punch mark were blanketed with rust, and therefore

should have suffered equally intense corrosion if differential aeration were at work. The third explanation appeared rather unlikely, as the specimens had been exposed to dry air for a considerable time between punching and immersion.

Mr. J. H. WHITELEY (Consett) said that he did not think that placing pieces of metal on wax blocks in a tank of salt water was a really scientific way of dealing with the corrosion problem. The author came to the conclusion that the corrodibility of steel was not increased to any appreciable extent by cold-working. That conclusion was certainly supported by the fact that the edges of a sheared plate, which were of course severely cold-worked, did not appear to corrode any faster than the remaining portion of the plate; and to that extent he agreed with the author. On the other hand, he had seen cases which seemed to point to the fact that a certain degree of stressing could cause corrosion. Quite recently he had examined a ship returned from her first voyage, and he found a series of corrosion pits in vertical lines on the bent strake carrying the bilge keel. Those lines were almost regularly spaced about 2 ft. apart, and seemed to suggest that cold-working by bending had made the steel more susceptible to corrosion. He would be glad to have Dr. Friend's opinion on the matter.

CORRESPONDENCE.

Mr. T. G. ELLIOT (Sheffield) wrote that the influence of overstrain on the corrosion of steel formed an important study, and the thanks of those interested were due to Dr. Friend for his careful and painstaking work. The various points mentioned on p. 640 were well considered, and the scheme of tests based upon them, so far as Dr. Friend had attempted at present, was a most useful contribution to the important field of investigation he had planned.

The fact that one series extended over a period of three years should, he thought, make the results additionally useful, and in that connection he would like to ask Dr. Friend whether the water was changed during that time.

The conclusions, one would think, would be welcomed by the engineer, indicating as they did that, under conditions approximating to those obtaining in practice, statically strained wrought iron and mild steel behaved in salt water very similarly to unstrained material.

Mr. E. J. McKAIG (Weston-super-Mare) wrote: Although Dr. Friend does not claim to be able to put forward any positive information as a result of the tests described in the paper, nevertheless they are interesting and of value. He makes it quite clear in his concluding remarks that he does not place greater reliance on the results than they

merit, being, as they are, laboratory tests, no doubt carried out with great care and precision, but more or less under what might be called artificial conditions. The writer feels that the last few lines of the final paragraph, although stated as conjecture, possibly explain the more or less negative results of the laboratory tests.

In all the tests described the specimens had been subject to stress, and were consequently strained. They were, however, at rest, and such a state of affairs rarely occurs in practice. It is not intended to infer that all steel structures, ships, &c., are in a continual state of alternating stress, but they must from time to time be subject to stress in varying degree, with resultant strain. This now is a very different condition from that under which Dr. Friend's tests were carried out. Although he expressly warns the reader not to read any more into the results than they can legitimately bear, it appears only reasonable to assume from the results that actually strained metal in corrosive media behaves within limits no differently from unstrained. This being so, it would be a welcome addition to the paper if Dr. Friend would give his views as to whether the mechanical process of straining has not a greater bearing on the result than the actual strain.

This assumption makes it necessary to accept the "crack theory" which is not perhaps universally accepted, cracks being mentioned by Dr. Friend as being visible when the metal is strained. Still there is evidence that the accelerated corrosion of metals under strain may be due to primary surface corrosion operating in a mechanical manner in the surface cracks, or, rather, the opening of the crack varying with the strain must tend to force off the layers of rust and expose a new surface to the corroding influence.

It has been established, practically beyond doubt, that corrosion is accelerated on surfaces that are rubbed or touched¹ from time to time, and it is not unreasonable to assume that the mechanical process of straining and unstraining would have a similar result. Carrying this reasoning further, might this not account for the better preservation of mild steel that has been painted whilst hot,² the result of painting on the heated surface being that the cracks become filled with a more or less plastic material.

Mr. S. A. MAIN (Sheffield) wrote that the author's results would undoubtedly tend to strengthen the conclusion that in neutral media strained iron and ordinary steel were little, if at all, more corrodible than unstrained. It would not cause particular surprise to find that true of uniformly strained material, but the similar results with strained and unstrained material together in unequally deformed iron and steel would, he thought, modify general ideas. While, as the author rightly advised, the results must be limited in their application,

¹ McKaig and Friend, *Institution of Civil Engineers. Fourth Interim Report*, 1924.

² *Ibid.* *Seventh Interim Report*, 1927.

they would, he thought, introduce a doubt into most people's minds before they, as hitherto, assigned strain as the cause in some cases of practical corrosion.

Although, from the general point of view, tests under practical conditions of exposure were undoubtedly desirable, in the present case they would not be easy to arrange with the same necessary attention to detail nor under the same careful control as in the laboratory, and he saw no reason to doubt the indications of the present tests.

In carrying out tests of that nature—that is, upon ordinary steel and iron which was commonly used without being submitted to heat treatment—there was a fundamental difficulty, arising from the fact that the materials were already in a varying state of strain. Conclusions had, therefore, to be drawn from the behaviour of specimens in which varying controlled degrees of strain were superposed upon other strains of undetermined amounts. In those circumstances the indications obtained by the author in the tests comprised in series I. to III. must be regarded as satisfactory. In the subsequent series IV. to VI., the excellent concordance of the results no doubt owed something to the fact that in those cases the complicating influence of previous strain had largely been removed by previously annealing.

In his opinion the tests might be continued with advantage under conditions of aerial and alternate wet and dry exposure.

Dr. J. NEWTON FRIEND, in reply, wished to point out at once that people who took up long-period corrosion tests always laid themselves open to special criticism. The corrosion tests he described were mapped out eight years ago. During the intervening period a great deal more had been learned about corrosion than was known at the time when the experiments started; consequently one was now able to look back on a scheme eight years old and view it with wider knowledge than was possible when the scheme was first inaugurated. That was a peculiarity of corrosion experiments which did not obtain with work that could be laid down a few months, or even a year, before the tests were completed.

Two of the speakers—possibly three—assumed he had made a statement which nowhere occurred in the paper. The conclusion had *not* been drawn that stress did not accelerate corrosion. He had been most particular in pointing out that it had not appreciably accelerated corrosion *under the conditions of the experiments described*. He felt that should be emphasised because, after all, everyone knew that tests of the kind in question did not necessarily conform to practice. He hoped that other investigators might be able to carry out experiments on a larger scale; the laboratory tests described in the paper were satisfactory when they were initiated, but experiments on a large scale were wanted at the present time.

Dr. Bengough thought that the conclusions reached in the paper
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must be taken as applying only to the particular experimental conditions detailed therein. As stated in the paper, however, that was all that was claimed.

He (Dr. Friend) was in complete agreement with Dr. Bengough's statement that in corrosion work it was necessary "to gather together quantitative data obtained under perfectly definite and known conditions." He fully appreciated the complexity of the problem, and was well aware of the many factors affecting corrosion, each of which should be tracked down separately; as long ago as 1911 he (Dr. Friend) directed attention¹ for the first time to those factors, though in some cases the nomenclature of those days was slightly different.

Dr. Bengough regarded as a "serious omission" the fact that the distances between the specimens in the corrosion tank were not given, and added that "if they were too close together, they would interfere with each other's oxygen supply." In 1912² he (Dr. Friend) directed attention to the importance of keeping the specimens sufficiently far apart, and experimentally determined the space that should be allowed between them. Dr. Bengough might rest assured that that precaution was not forgotten in the present research. The distance of the specimens from one another was greater than the minimum required by the formula given in the reference cited. Each specimen was thus free to corrode independently of the others. He was a little surprised that Dr. Bengough should not give him credit for taking such an elementary precaution.

Dr. Bengough appeared to be worried at the good agreement between the duplicated controls. That agreement was due in part to the careful annealing effected at Messrs. Hadfields, and in part to the extreme care taken by himself (Dr. Friend) in the course of the experiments to ensure identical external conditions for all the specimens.

Dr. Bengough stated that, allowing for differences in areas, the wrought iron in Table III. corroded 50 per cent. more rapidly than that in Table V. He (Dr. Friend) must draw attention to the fact that the area of *L1* exposed to corrosion was 1.61 sq. in., and of *HBBB1*, 17.32 sq. in.; hence the losses in weight per 100 sq. in. were 20.7 and 26.2 grm. respectively—a difference of 21 per cent. only. Further, Dr. Bengough assumed that the two series were directly comparable. That was not the case, since (i) Series II. and IV. were not exposed over quite the same suite of months in the two years mentioned, and (ii) Series II. lay only 5 cm. below the surface of the salt water; Series III. lay 10 cm. below. It would also be noted that *HBBB1* contained more than twice as much sulphur as *L1* (see Table I.). There were several reasons, therefore, why they should not corrode at equal rates.

It was a matter for regret that Dr. Bengough should have confined his remarks to what were obviously hasty criticisms. One searched

¹ Friend, "The Corrosion of Iron and Steel." Longmans, 1911.

² *Journal of the Iron and Steel Institute*, 1912, No. I. p. 259.

in vain for any helpful suggestion as to how the research might have been improved.

Mr. Whiteley's examples appeared to be apt illustrations of the difference between static and dynamic conditions, and to support the conclusions of the present paper. Regarding his criticism of the method of experiment, he (Dr. Friend) would welcome any suggestions from Mr. Whiteley for an improved method.

He thanked the other gentlemen for their remarks. In reply to Mr. Elliot, the water was not changed during the three years, save that evaporation was made good with tap water. The corrosion tank held nearly a ton of salt water, and it was thought that change of water was not so necessary as in laboratory beaker tests. Undoubtedly, as Mr. McKaig said, the mechanical process of straining was highly important. He was glad to find himself in general agreement with the remarks of Mr. Evans.

THE RAPID NORMALISING OF OVERSTRAINED STEEL.¹

By W. E. WOODWARD, M.A. (CAMBRIDGE).

PART I.—NORMALISATION BY DIRECT CURRENTS.

THE specimens employed in the first part of this work were all prepared from a mild steel containing 0·16 per cent. of carbon, which had been given various permanent sets. They were normalised by passing very large currents directly through the specimens, and the results obtained were so extraordinary that they were thought worthy of embodiment in a paper.

The most remarkable features in connection with the electrical restoration of the steel were the uniformity of the results and the rapidity with which the specimens were restored to perfect elasticity. The restoration was also carried out by the ordinary process of normalising in an electric resistance furnace, but the results were not so uniform, and the specimens suffered from the effects of scaling. As the electric treatment was carried out in air, a direct comparison could hardly be obtained by normalising *in vacuo*.

The Cambridge University Engineering Laboratory possesses a Lahmeyer duplex dynamo which had belonged to a German submarine. By performing the Hopkinson-Kapp test on the combined plant a large direct current can be obtained at a very low voltage. Currents up to 750 amp. can be used for 1 hour, and the plant can be loaded continuously up to 600 amp.

The first set of tests was performed upon specimens 0·5 in. in diameter. The steel possessed in the "as received" condition the following properties :

Yield point	.	.	.	.	25·90 tons per sq. in.
Ultimate stress	.	.	.	.	31·55 " "
Elongation	.	.	.	.	45 per cent. on 2 in.

¹ Received January 10, 1928.

Its complete analysis was :

	%
Carbon	0.160
Manganese	0.385
Silicon	Trace
Sulphur	0.036
Phosphorus	0.041
Nickel	0.960

The microstructure in the "as received" condition is shown in micrograph Fig. 1 (Plate XLII.).

In the first series of tests a definite extension was given to the various specimens by means of a tensile testing machine. Table I. gives the figures for the yield point and the loads required to produce different permanent sets.

TABLE I.—*Tests on Mild Steel.*

Mark.	Diameter. In.	Yield Point. Tons per sq. in.	Set. %	Load for this Set. Tons per sq. in.
2	0.400	25.90	4	25.90
5	0.397	25.80	8	28.88
8	0.397	25.90	12	30.65

The above were in the "as received" condition before being strained.

After straining, the specimens were normalised by passing currents ranging up to 600 amp. through the steel. The time occupied in raising them to the A_{c_3} point varied from 4 min. 30 sec. to 3 min. 40 sec., according to the current density. The specimens were taken out of the clamps as soon as the current was switched off and allowed to cool on the floor. They were then retested, with the results shown in Table II., the tests in this case being carried out to destruction.

TABLE II.—*Tests on Mild Steel after Normalising Electrically.*

Mark.	Diameter. In.	Yield Point. Tons per sq. in.	Set. %	Load for this Set. Tons per sq. in.	Ultimate Stress. Tons per sq. in.
2	0.392	23.40	4	24.90	31.75
5	0.384	23.40	8	28.70	31.75
8	0.378	23.50	12	30.28	31.96

The equalisation effected in the yield points of the specimens which had previously received widely different permanent sets is remarkable. The breaking loads also correspond to within less than 0.25 ton per sq. in., and are not far removed from the figure given by another "as received" specimen, namely, 31.55 tons per sq. in.

Crystal distortion even with 12 per cent. permanent set is not conspicuous under the microscope, and for this reason a much more spectacular test was undertaken, with remarkable results.

A specimen similar to those mentioned above was loaded until a neck was well formed, giving an extension of 41 per cent. on 2 in. The original parallel portion was 0.400 in. in diameter, and the diameter of the bottom of the neck was 0.253 in. The specimen was then turned parallel to this latter figure, and was then treated electrically in order to determine whether the elasticity could be restored. The time required to reach the A_{c3} point was only 55 sec. in this case, and the specimen was held at this temperature for a further minute. The new figures on retesting were :

Yield point	.	.	.	.	23.55 tons per sq. in.
Ultimate stress	.	.	.	.	31.65 „ „

A perfect cup and cone fracture was obtained.

Micrographs Figs. 2 and 3 show the steel with 41 per cent. set and a similarly strained specimen after restoration. The latter reveals a very fine-grained structure without any trace of the distortion which is so pronounced in the former micrograph.

Table III. records the test values for a set of specimens which were strained in a similar way to those in Table II., but which were normalised by heating in an electric furnace maintained at 880° C. for 1 hour previous to the insertion of the specimens. It required 45 min. for the pyrometer to reach this temperature again after the cold specimens had been placed in the furnace. Subsequent tests proved that the elasticity of the steel had undoubtedly been restored, but the results were not so remarkably uniform as those produced by restoring electrically. Also, the specimens were reduced in diameter, owing to the presence of scale on the surface.

Specimens were next tested in torsion. One of the tensile test-pieces was twisted so that the reduced portion, 2.75 in. long,

was twisted through 810° . The magnitude of the torsion couple was 853 in.-lb. After normalising by electric heating in just under 5 min., the same couple produced the same twist, so that

TABLE III.—*Tests on Mild Steel Normalised in an Electric Furnace.*

Mark.	Diameter. In.	Yield Point, Tons per sq. in.	Set. %	Load for this Set. Tons per sq. in.	Ultimate Stress. Tons per sq. in.
3	0.400	26.12	4	26.12	...
3a	0.391	23.32	4	25.64	30.78
6	0.399	25.92	8	28.86	...
6a	0.383	23.75	8	27.65	31.22
7	0.397	26.40	12	30.22	...
7a	0.373	24.06	12	29.85	31.38

Specimens 3a, 6a, and 7a above were the original specimens 3, 6, and 7 after normalising in the electric furnace.

the total twist was 1620° in 2.75 in. This could be seen clearly upon a specimen which had had two lines scribed on its surface ; one was twice the pitch of the other. Micrographs Figs. 4 and 5 show the twisted, and twisted and restored, structures of two identical specimens.

At the suggestion of Professor C. E. Inglis, O.B.E., M.Inst.C.E., whose kindly interest in the work is hereby acknowledged, some specimens were overstrained in tension and subjected to rotating beam tests. The machine used was of the "Farmer" type. Similar pieces were overstrained and normalised by electric heating before being tested.

The details of the tests are given in Table IV. It would appear that the ordinary process of normalising does not entirely wipe out the effects of a large amount of overstrain. The author ventures to suggest that the electric current can heal material in which the effects of overstrain have gone too far to be healed by ordinary methods of treatment.

A further set of tests was carried out upon a bar of mild steel selected at random from the stock of $\frac{7}{8}$ -in. rounds used for laboratory experiments. The steel was supplied reeled, thus giving a rather high yield point. After straining so as to produce a 30 per cent. permanent set, the bar was turned down to 0.4 in.

in order to permit a fairly rapid rise of temperature. The turned bar required 5 min. 15 sec. to come up to 880° C. by the electric normalising process. After a second tensile test the specimen

TABLE IV.—*Rotating Beam Tests on Mild Steel.*

	1.	2.	3.	4.
Condition	As received	26% permanent set	As No. 2, and normalised in usual manner	As No. 2, and normalised electrically
Load on pan, lb. . .	92·5	94·5	93·5	93·5
Diam. of reduced section, in. . .	0·297	0·299	0·298	0·298
Stress, lb. per sq. in. .	± 36,100	± 36,100	± 36,100	± 36,100
Reversals of stress for fracture	9,600,000 unbroken	5,450	2,942,950	10,000,000 unbroken
Variations during test	Nil	Nil	Nil	Nil
Static elastic limit, tons per sq. in. . . .	25·90	...	...	...
Static yield point, tons per sq. in. . . .	25·90	...	23·75	23·4

was turned down to the new reduced diameter, normalised electrically in 115 sec., and then retested for a second time. The results are given in Table V.:

TABLE V.—*Tensile Tests on Mild Steel R.*

Condition.	Yield Point. Tons per sq. in.	Ultimate Stress. Tons per sq. in.
"As received" . . .	23·78	30·00
After first normalising .	22·70	30·71
After second normalising .	22·65	30·53

In each of the last two tests the point given by 30 per cent. extension was exceeded, and the load was increased until a neck started to appear.

The evidence seems to prove that the elastic properties of specimens of mild steel which have been seriously overstrained can be fully restored in an exceedingly short space of time by means of a direct current passed through the material so as to heat it above the point of recrystallisation. The resistance to

fatigue of specimens with a similar amount of overstrain can apparently also be completely restored in this manner. Furthermore, it would appear that the ordinary method of normalising does not effect such perfect restoration of the resistance to fatigue, as is evidenced by the figures given in Table IV.

PART II.—NORMALISATION BY ALTERNATING CURRENTS.

The second portion of the research consisted in carrying out experiments of a similar nature upon three different carbon steels, but using alternating currents for the production of the heating effect. At the author's request Dr. C. G. Lamb kindly designed a transformer which could produce and carry safely in its secondary coils about 2000 amp. at about 6 v. This very large current enabled suitable specimens of the same cross-section as those employed in the first part of the work to be heated to melting point in 20 seconds. After a considerable number of experiments had been carried out it was found that a heating period of about three minutes was all that was required to effect the restoration of the material after straining.

The analyses of the three steels are set out in Table VI. :

TABLE VI.—*Analyses of Steels experimented upon with Alternating Currents.*

Mark.	Carbon. %	Silicon. %	Manganese. %	Sulphur. %	Phosphorus. %	Nickel. %
FB . . .	0·15	0·12	0·56	0·024	0·046	0·18
FC . . .	0·31	0·17	0·61	0·039	0·042	Nil
FD . . .	0·48	0·26	0·58	0·017	0·019	0·43

The following three series of tests were carried out upon all three materials.

Series A.—Tensile Tests on Specimens with various Extensions.
—Tensile tests were carried out on the three steels, the specimens being given the following permanent sets: Steel FB was given an extension of 20 per cent., steel FC 15 per cent., and steel FD 10 per cent. Tensile tests were then carried out, with the results recorded in Table VII.

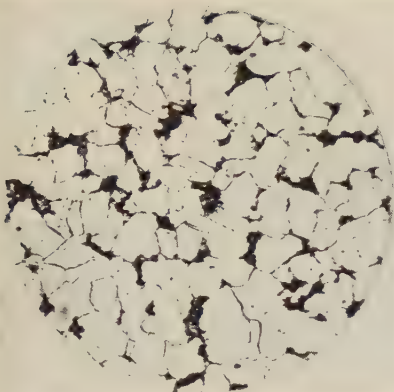


FIG. 1.—Steel 9, carbon 0.16 per cent. ; as received. Transverse section. $\times 450$.

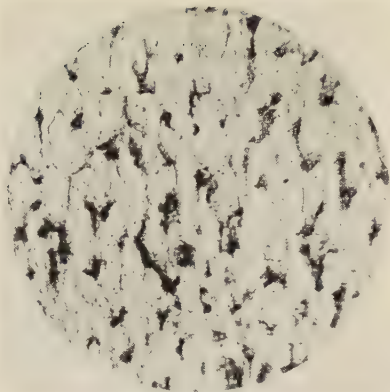


FIG. 2.—Steel 9, carbon 0.16 per cent. ; strained, 41 per cent. extension. Longitudinal section. $\times 450$.

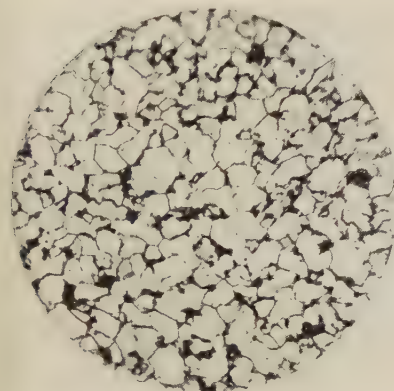


FIG. 3.—Steel 9, carbon 0.16 per cent. ; normalised, after straining, by 600 amp. D.C., in 2 min. $\times 450$.

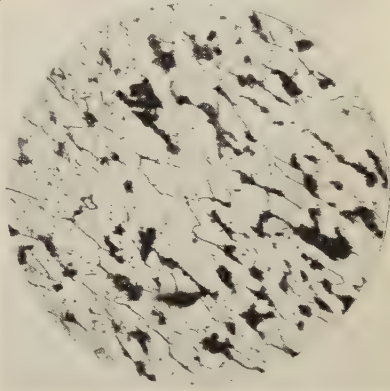


FIG. 4.—Steel 9, carbon 0.16 per cent. strained by twist of 300° per in. Longitudinal section. $\times 450$.

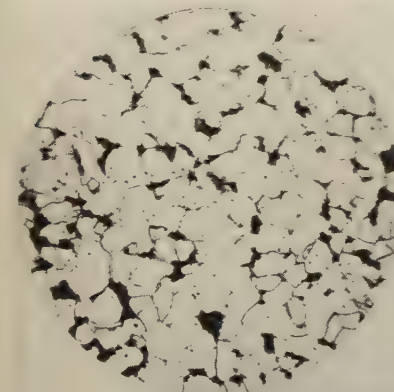


FIG. 5.—Steel 9, carbon 0.16 per cent. ; normalised, after straining, by 600 amp. D.C. in 5 min. $\times 450$.

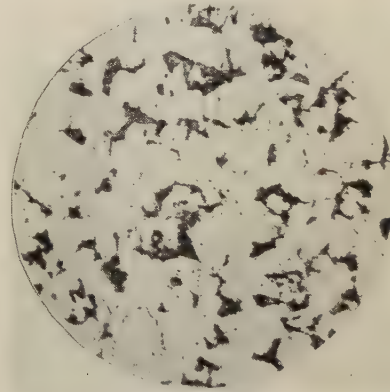


FIG. 6.—Steel FB, carbon 0.15 per cent. ; as received. Transverse section. $\times 450$.

NOTE : The above micrographs have been reduced to four-fifths linear in reproduction. [To face p. 666

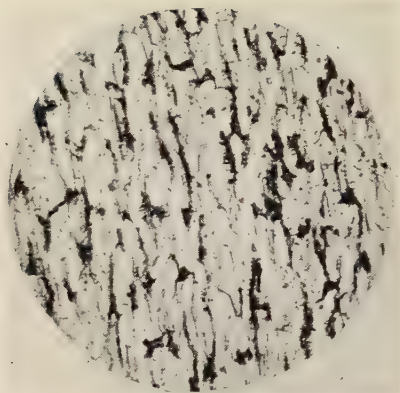


FIG. 7.—Steel FB, carbon 0.15 per cent. ; strained, 40 per cent. extension. Longitudinal section. $\times 450$.

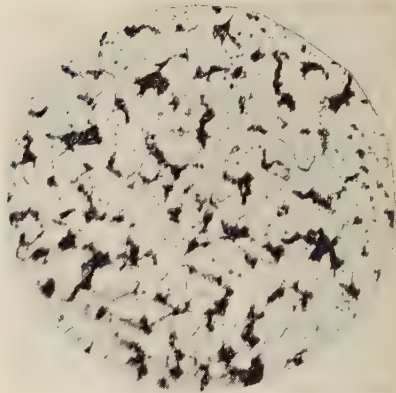


FIG. 8.—Steel FB, carbon 0.15 per cent. ; normalised, after straining, by 600 amp. A.C. in 3 min. $\times 450$.



FIG. 9.—Steel FC, carbon 0.31 per cent. ; strained, 30 per cent. extension. Longitudinal section. $\times 450$.

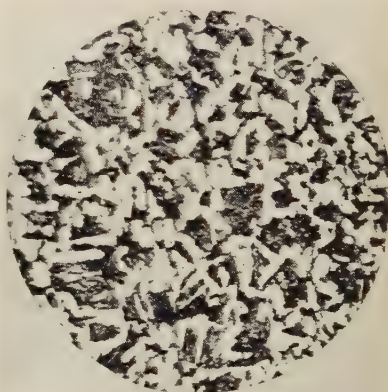


FIG. 10.—Steel FC, carbon 0.31 per cent. ; normalised, after straining, by 600 amp. A.C. in $2\frac{1}{2}$ min. $\times 450$.

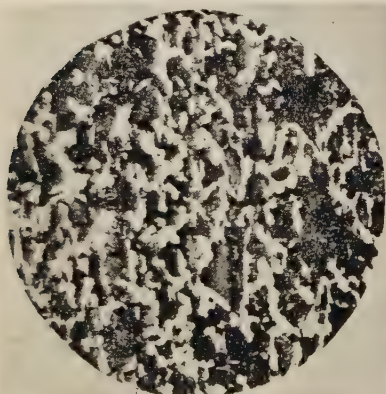


FIG. 11.—Steel FD, carbon 0.48 per cent. ; strained, 20 per cent. extension. Longitudinal section. $\times 450$.

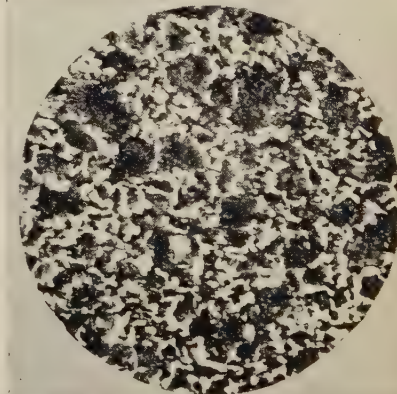


FIG. 12.—Steel FD, carbon 0.48 per cent. ; normalised, after straining, by 600 amp. A.C. in $2\frac{1}{2}$ min. $\times 450$.

NOTE: The above micrographs have been reduced to four-fifths linear in reproduction.

TABLE VII.—*Tensile Tests before Normalising with A.C.*

Mark.	Diameter. In.	Yield Point. Tons per sq. in.	Set. %	Load for this Set. Tons per sq. in.
FB2T	0·397	24·90	20	32·35
FC3T	0·393	29·00	15	40·75
FD1T	0·372	35·00	10	49·55

The specimens were then normalised by passing currents ranging up to 600 amp. through the steel. The time occupied in taking them up to A_{c_3} or $A_{c_{23}}$ was $2\frac{1}{4}$ min., and they were held at this point for a further $1\frac{1}{2}$ min. The specimens were taken out of the clamps as soon as the current was switched off and were allowed to cool on the floor. They were then retested as shown in Table VIII.:

TABLE VIII.—*Tensile Tests after Normalising with A.C.*

Mark.	Diameter. In.	Yield Point. Tons per sq. in.	Set. %	Load for this Set. Tons per sq. in.
FB2T	0·356	24·25	20	31·80
FC3T	0·366	27·35	15	40·50
FD1T	0·356	34·30	10	48·85

A comparison of the figures in Tables VII. and VIII. shows that the material has been restored to a remarkable extent; not, however, to such a degree as was obtained by the use of direct current, but yet sufficiently for all practical purposes.

Specimens of the materials in the strained, and strained and restored conditions, were polished and etched, and micrographs prepared. The strain given to FB was 40 per cent., to FC 30 per cent., and 20 per cent. to FD. Micrographs Figs. 6 to 8 (Plates XLII. and XLIII.) show FB "as received," in the strained condition, and in the strained and restored condition respectively. The current employed for the normalising process was 600 amp. and the time of heating and soaking was 3 min. It will be observed that the grain-size of the restored specimen is much smaller than that of the steel in the "as received" condition. Micrographs Figs. 9 to 12 show FC and FD in the strained, and strained and restored

conditions respectively. In each case the restoration was effected in $2\frac{1}{2}$ min., and in neither micrograph of the restored specimens is there visible any trace of the great distortion which is apparent in the micrographs of the steels in the strained state.

Series B.—Torsion Tests with various Amounts of Twist.—A specimen of steel FB was twisted through 720° on a 3-in. length (240° per in.), normalised in 3 min., and then twisted through a further 720° . The specimen was then normalised a second time and twisted through a third 720° , so that the original line which had been scribed upon the surface showed six complete revolutions in 3 in. After normalising, the specimen was untwisted through 2160° with two further normalising treatments. The entire test, including all the heat-treatment processes, was carried out in less than two hours.

A similar specimen of FC was twisted through 630° (210° per in.) and then twisted through a further 630° after one intermediate normalising process. The test-piece was then normalised, and was subsequently untwisted through 1260° with one intermediate treatment. The entire test occupied one hour.

FD was tested in precisely the same way as FC, except that the total twist was only 720° (two twists, each of 120° per in.). The total time required to carry out the tests was one hour.

Series C.—Rotating Beam Tests.—Rotating beam tests were carried out on the three steels FB, FC, and FD. Specimens of each steel were examined in the condition as received. Other test-pieces were given the following permanent sets before testing : FB 20 per cent., FC 15 per cent., and FD 10 per cent. A third set of specimens was given the foregoing permanent sets and was then restored electrically (FB in 3 min., FC and FD in $2\frac{1}{2}$ min.) before applying the rotating beam tests. The results of all these tests are collected together in Table IX.

The loads were, with one exception, too heavy to allow the specimens to withstand 10,000,000 reversals without fracture, but in each case the restored specimen withstood a greater number of reversals than when in the "as received" condition.

The evidence seems to show that an alternating current, passed directly through the specimen so as to heat it above the upper critical point, can also be used to restore fully, after serious overstrain, the elastic properties of the three classes of carbon

TABLE IX.—*Rotating Beam Tests on Steels FB, FC, and FD.*

	Steel FB.			Steel FC.			Steel FD.		
	1.	2.	3.	4.	5.	6.	7.	8.	9.
Condition	As received	20% permanent set	As 2, and restored in 3 min.	As received	15% permanent set	As 5, and restored in 2½ min.	As received	10% permanent set	As 8, and restored in 2½ min.
Load on pan, lb.	96.50	96.50	96.50	113.50	113.50	113.50	132.50	132.50	132.50
Diam. of reduced section, in.	0.298	0.298	0.298	0.298	0.298	0.298	0.298	0.298	0.298
Stress, lb. per sq. in.	± 36,400	± 36,400	± 36,400	± 44,000	± 44,000	± 44,000	± 51,520	± 51,520	± 51,520
Reversals of stress for fracture	3,666,400	10,000,000 unbroken	5,004,500	418,000	325,000	429,000	384,900	1,522,850	776,350
Variations during test	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
Static elastic limit, lb. per sq. in.	44,700	...	...	56,400	...	...	68,350	...	...
Static yield point, lb. per sq. in.	55,185	55,185	54,220	63,430	63,430	62,020	78,140	78,140	76,830

steel examined. Similarly, the resistance to fatigue can be perfectly restored in this manner.

CONCLUSIONS.

It appears from the tests described above, that in order to obtain absolutely concordant results, the normalising must be effected by means of direct currents. For all practical purposes, however, the use of alternating currents seems to be sufficient. In both cases the grain-size can be carefully controlled and rendered extremely small in an astonishingly short space of time.

Further experiments on the effects of time and rate of heating are being carried out, and it is hoped to embody them in another paper in the near future.

The author's best thanks are due to his assistant, Mr. D. W. Searle, for his skill in preparing the micrographic specimens and micrographs. He is also much indebted to Dr. C. G. Lamb for the design of the transformer; to Mr. F. W. Cowles, B.A., for help in running the Lahmeyer plant; and to Mr. A. W. Barker for the careful machining of the various test-pieces.

After the above paper had been submitted to the Iron and Steel Institute the author's attention was drawn to British Patent Specification No. 212,887: application date, February 25, 1924. This specification is an essay upon the advantages obtained by restoring the crystalline structure of metals by heating them by means of electric currents.

DISCUSSION.

Mr. E. A. ATKINS (Warrington) asked what was the particular virtue of using direct current or alternating current except as a source of heat; it did not appear to be in any way novel. Electric current, both direct and alternating, was, of course, used in the wire trade for heating purposes, and its only advantage was that thin wire could be heated up out of contact with the atmosphere. Both the wire and sheet trades dealt with a very mild steel, and after it had been work-hardened it was a great advantage to heat it up quickly and cool it down normally to render the material tough.

Mr. H. SUTTON (Cove, Hants.) asked how the temperatures of the steel normalised electrically were measured. He thought that was rather important, because in order satisfactorily to compare the properties of the electrically normalised steel with those of steel normalised in the ordinary muffle, one should have strictly comparable methods of measuring the temperature.

Mr. Atkins had touched on a point which was in his own mind, namely, the importance of distinguishing if there were any difference between the electrically normalised and the ordinary normalised steels. If there were some difference, he thought probably the most careful measurement of temperature would be justified in order definitely to place it on record.

One realised that a small difference of normalising temperature might have a very profound effect on the properties of a steel, and from his interest in some previous work on a similar process he could say that it was very easy to overheat steel slightly by passing current through it. One had always to bear in mind the cooling effect of the air on the outer skin. Some years ago attempts were made to heat-treat strip steel by that method, and although the apparent temperatures, judged by the optical pyrometer, were in the normal range, the properties of the treated steels were such that the conclusion that the steel had definitely been overheated was inevitable.

Mr. W. E. WOODWARD, in reply, said he was interested to hear Mr. Atkins speak of the use of electricity for heating up wires. He knew that had been done before, but one of the reasons that led him to do the work described in the paper was that one used an incredibly small amount of power per specimen. Using the alternating current machine on the transformer described, the whole work of heating up took about $2\frac{1}{2}$ minutes for the specimens he had been using; he had been taking 100 v. and 30 amp. on the primary side and transforming it down suitably—that was, 3 kw. for about 3 minutes altogether.

Thus he could treat a great many specimens for the same price as a small number in an electric muffle.

He ventured to think there was something in the electricity over and above its use as a mere source of heat. The figures obtained in the experiments described, which were not the only ones he had obtained in the course of two years' work on the subject, by normalising by means of current passed through the material, were very much better than those which had been pyrometrically controlled fairly accurately in the ordinary muffle.

In reply to Mr. Sutton, the temperatures were measured by various methods; he generally tried to arrange a check between a rhodium-platinum thermocouple bound on to the specimen by means of asbestos, and an optical pyrometer focused through a little slot in the asbestos. He came to the conclusion that the two methods did not give the same readings, but by making several experiments before those quoted in the paper were carried out, he found that it was possible to get to a temperature which did compare very accurately with the observed critical points of the specimens employed. By taking a cooling curve and using both methods, but preferably the pyrometer bound on to the specimen, it was possible to get a very close approximation to the actual normalising temperature.

He offered the following theoretical explanation of the difference obtained with direct current and alternating current: On passing a maximum current of 2000 amp. through the specimens and getting them up to the temperature in about 16 sec., there was no doubt that the heat was not uniform across the section; the skin effect of the alternating current was quite noticeable even with the 90 periods of the Cambridge supply. With the alternating current a definite time was necessary for the heat to be conducted through the section, whereas with direct current the cross-section was heated uniformly.

THE RECOVERY AND SINKING-IN OR PILING-UP OF MATERIAL IN THE BRINELL TEST, AND THE EFFECTS OF THESE FACTORS ON THE CORRELATION OF THE BRINELL WITH CERTAIN OTHER HARDNESS TESTS.¹

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1. *Introduction.*

BRINELL impressions made on different materials may vary considerably in form. In some cases the material is raised and "piled-up" round the impression, while in others it may be "sunk-in" so that the circumference of the impression is considerably below the original surface. In addition, the impression may be "flattened"—that is, its depth may be less than that calculated from its diameter and the curvature of the Brinell ball used.

In the present research, measurements have been made of the "sinking-in" or "piling-up" and "flattening" and "elastic recovery" of 10-mm. ball Brinell impressions on a number of materials, representative of practically all types that are subjected to the Brinell test.

Scleroscope, pendulum, and 90° cone tests were also made on the same materials, and their correlation with the Brinell test is discussed.

About forty annealed and tempered carbon and chromium steels of various hardnesses from 100 to 700 Brinell, which gave the average curves plotted in Fig. 2, were tested, and in addition certain extreme types of material were examined, such as certain cast metals which showed pronounced sinking-in, certain cold-hammered metals which showed pronounced piling-up, and vulcanite which showed pronounced flattening and elastic recovery.

¹ Received August 15, 1927.

2. *Method of carrying out 10-mm. Ball Brinell Tests and Measuring Sinking-In or Piling-Up and Flattening of resulting Impressions.*

Brinell impressions of various sizes, obtained by selecting various suitable loads between 0 and 20,000 kg., were made on each of the nineteen different materials shown in Table II. The results of the Brinell tests were plotted logarithmically according to Meyer's formula, $P = ad^n$ (where P = load applied in kg., d = diameter of impression produced in mm., and a and n are two constants depending on the composition and condition of the material tested), and the values of n and $n + \log a$ were estimated.

The Brinell results on all the materials tested obeyed Meyer's law, with the exception of those on manganese steel, which will be referred to again later.

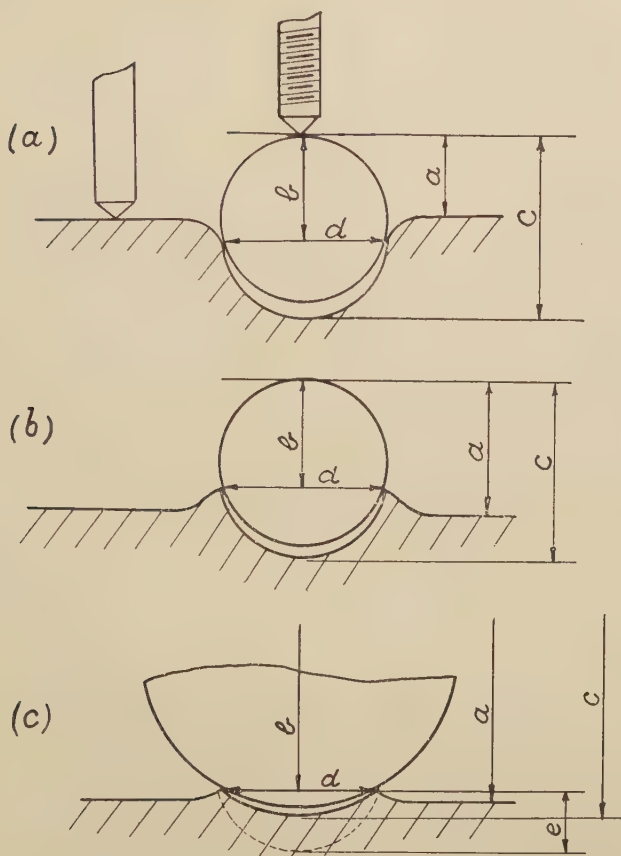
Measurements of sinking-in or piling-up and flattening were made in the manner illustrated in Fig. 1. For most materials an 11.11 mm. diameter steel ball was placed in the Brinell impressions, and spherometer measurements were made to its topmost point. When the flattening was considerable, a larger ball had to be used (see Fig. 1c), to obviate the ball resting on the bottom of the impression instead of on the circumference.

3. *Constancy of Sinking-In or Piling-Up when Expressed as a Percentage of the Depth.*

The results of spherometer measurements of sinking-in and piling-up on four representative materials are shown in Table I. It will be seen in column 8 that the sinking-in or piling-up values increase with increasing size of impression, and are, in fact, proportional to the corresponding depths of impression in column 3. In other words,

$$\frac{\text{Piling-up or sinking-in}}{\text{Depth of impression calculated from diam.}} = \text{constant}$$

for a given material, irrespective of the size of the 10-mm. ball impression, as shown by the results in columns 9 and 10.



- a is obtained from spherometer reading ;
 b is calculated from a and d (diam. of impression measured with a travelling microscope) and the radius of the steel ball resting in the impression ;
 $b - a$ = sinking-in in Fig. (a) ;
 $a - b$ = piling-up in Figs. (b) and (c) ;
 c is obtained from spherometer reading ;
 $c - b$ = measured depth of impression ;
 e (Fig. (c)) = depth of impression, calculated from measured diam., assuming 5-mm. radius of curvature ;
 $e - (c - b)$ = flattening, *i.e.* difference between depth calculated from diam. and measured depth.

FIG. 1.—Spherometer Measurements of Brinell Impressions.
 (a) Sinking-in, (b) piling-up, and (c) flattening.

TABLE I.—*Spherometer Measurements of the "Sinking-In" or "Piling-Up" and "Flattening" of 10-mm. Ball Brinell Impressions of Various Sizes on Representative Materials.*

	Cast Copper, showing Pronounced Sinking-In.				Tempered Carbon Steel, showing Normal Piling-Up.				Cold-Hammered Aluminium, showing Pronounced Piling-Up.				Black Vulcanite, showing Pronounced Flattening.			
1	Load applied. Kg.	1000	1500	2500	4000	5000	6500	10 000	500	1000	2000	3000	400	500	750	1000
2	Diameter of impression. Mm.	5.80	6.85	8.28	9.71	4.21	4.68	5.34	3.53	4.96	7.15	8.68	5.42	6.32	7.62	8.57
3	Depth of impression calculated from diam. Mm.	0.93	1.36	2.21	3.81	0.46	0.58	0.77	0.32	0.67	1.50	2.53	0.80	1.13	1.76	2.45
4	Depth measured between circumference and bottom of impression. Mm.	0.92	1.35	2.19	3.79	0.40	0.53	0.69	0.30	0.65	1.47	2.47	0.19	0.38	0.81	1.32
5	Flattening of impression (col. 3 — col. 4)	0.01	0.01	0.02	0.02	0.06	0.05	0.08	0.02	0.02	0.03	0.06	0.61	0.75	0.95	1.13
6	Flattening $\times \frac{\text{diameter}}{\text{depth}}$ (col. 5 $\times \frac{\text{col. 2}}{\text{col. 3}}$)	0.06	0.05	0.07	0.05	0.46	0.41	0.55	0.22	0.15	0.14	0.21	4.1	4.2	4.1	4.0
7	Average flattening $\times \frac{\text{diameter}}{\text{depth}}$	0.06				0.50				0.18				4.1		
8	Height of circumference of impression above (piling-up, +) or below (sinking-in, —) original surface. Mm.	—0.24	—0.36	—0.58	—1.11	+0.05	+0.06	+0.08	+0.13	+0.09	+0.21	+0.45	+0.70	+0.04	+0.07	+0.17
9	Percentage piling-up (+) or sinking-in (—), (col. 8 \div col. 3) $\times 100$	—26	—27	—26	—30	+12	+11	+12	+12	+30	+32	+31	+28	+21	+19	+21
10	Average percentage piling-up or sinking-in	27% sinking-in				12% piling-up				30% piling-up				21% piling-up		
11	Value of n in $P = a^n$	2.58				2.17				1.96				2.03		
12	Value of $n + \log a$	3.63				4.42				3.63				3.13		

TABLE II.—*Percentage Sinking-In or Piling-Up and Values of n in $P = ad^n$ with certain Materials.*

Material.	Percentage Sinking-In (—) or Piling-Up (+).	Value of n in $P = ad^n$.
Copper, cast	— 27	2.58
Copper, rolled and annealed at 900° C.	— 23	2.50
Copper, rolled and annealed	— 17	2.49
Magnesium, cast	— 22	2.42
Copper, rolled and annealed at 600° C.	— 8	2.34
Aluminium, rolled and annealed	— 4	2.32
Nickel, rolled and annealed at 900° C.	+ 2	2.28
Chromium steel, quenched	+ 4	2.27
Zinc, rolled and annealed at 150° C.	+ 4	2.26
Mild steel, annealed at 950° C.	+ 10	2.22
Chromium steel, tempered	+ 8	2.18
Carbon steel, tempered	+ 11	2.17
„ „ „	+ 12	2.17
„ „ „	+ 13	2.19
„ „ „	+ 21	2.03
Black vulcanite	+ 28	2.01
Copper, cold-hammered 20%	+ 28	1.96
„ „ „ 75%	+ 28	1.96
Aluminium, cold-hammered 90%	+ 30	1.96
Manganese steel, $d = 6.0$ mm.	+ 2	2.30
„ „ „ $d = 9.0$ mm.	— 9	> 2.30

4. Relationship between Percentage Sinking-In or Piling-Up Constants and Values of n in $P = ad^n$.

Results obtained in this manner on nineteen representative materials are shown in Table II., where the estimated values of n in $P = ad^n$ are also tabulated. It will be seen that there is a linear relationship, within the limits of experimental error, between the values of n and the amounts of sinking-in or piling-up : that is, when $n = 2.60$, sinking-in = 30 per cent. ; when $n = 2.30$, sinking-in or piling-up = 0 per cent. ; and when $n = 2.0$, piling-up = 30 per cent. Unsound cast materials show as much as 30 per cent. sinking-in, and cold-worked materials as much as 30 per cent. piling-up, annealed and tempered steels showing about 10 per cent. piling-up.

In the case of manganese steel, n was found to be approximately constant at 2.3, and the piling-up was constant at about 2 per cent. for impressions up to about 6 mm. in diameter. With

increasing loads and increasing diameters (and angles) of impression, however, the results no longer obeyed Meyer's law; n increased in value, and the piling-up decreased and gave place to sinking-in, which increased and reached a value of about 9 per cent. with a 9-mm. impression.

This fact of an increase in the value of n , corresponding with an increase in the sinking-in constant, is a confirmation of the relationship found between the two quantities above. (Incidentally, in a previous paper¹ the authors plotted the $P_{ult.}$ values (the load required to make a 10-mm. impression with a 10-mm. ball) of various materials against their ultimate stresses. A simple relationship was obtained for most materials, but manganese steel was a definite exception. The $P_{ult.}$ value for manganese steel was, however, incorrectly obtained by extrapolating the logarithmic plotting of 2.6 to 5.4 mm. diameter impressions. It has now been found that such extrapolation is not permissible for this exceptional material, and that the $P_{ult.}$ value so obtained would be considerably lower than the correct one. If the correct value had been obtained from impressions approaching 10 mm. in diameter, it would have given a point almost exactly on the " $P_{ult.}$ /ultimate stress" curve plotted in the paper.)

5. The Flattening of Brinell Impressions.

Heathcote,² Batson,³ and Honda and Takahasi⁴ have shown that the radius of curvature of a Brinell impression is always greater than that of the Brinell ball used. This flattening of Brinell impressions is due to the temporary and permanent deformation of the ball while the load is on, and to the elastic recovery of the impression on releasing the load.

The method of measuring this quantity is shown diagrammatically in Fig. 1c, and actual values are recorded in column 5 of Table I., where the flattening is shown as the difference between the depth measured between circumference and bottom of an impression and the depth calculated from its diameter, assuming

¹ *Journal of the Iron and Steel Institute*, 1924, No. I. p. 485.

² Heathcote, *Proceedings of the Institution of Mechanical Engineers*, 1918, November, p. 505.

³ Batson, *ibid.*, p. 574.

⁴ Honda and Takahasi, *Journal of the Iron and Steel Institute*, 1924, No. I. p. 320.

a 5-mm. radius of curvature (10-mm. ball). The flattening is most pronounced in the case of black vulcanite (Table I.). It will be seen that the flattening (column 5) increases with increasing size of impression, and appears to increase as the ratio—

$$\frac{\text{Depth of impression calculated from diameter}}{\text{Diameter of impression}}$$

increases. In other words,

$$\frac{\text{Flattening} \times \text{diameter of impression}}{\text{Depth of impression calculated from diameter}} = \text{constant}$$

for a given material (as shown by the results in column 6, Table I.), irrespective of the size of the 10-mm. ball impression. If flattening constants determined in this way on different materials be plotted against the respective Brinell numbers (10/3000/30), the results for steels of different hardnesses lie on a curve similar in form to Curve 1 in Fig. 2, and of about three-tenths its vertical scale. The results for cold-hammered materials lie a little above the average curve, while the result for black vulcanite, which possesses very high elastic recovery, is a long way above.

6. *The Elastic Recovery on Releasing the Load in the Brinell Test.*

The results in the present section have been obtained with an Amsler depth indicator¹ reading to 0.01 mm. Used in the ordinary way, this instrument measures the distance between the original surface of the material under test and the bottom of the impression produced, after releasing the load. A depth reading may, however, be made while the full load is on, and the difference between such a reading and one made in the usual manner on releasing the load gives the elastic recovery of the impression plus that of the ball, plus that of the ball-holder.

The elastic recovery of the ball-holder was measured by screwing off the steel cap, which normally rests on the specimen, and screwing on to the lowest point of the ball-holder a small clamp on which the sliding bolster then rested. A test specimen of steel was then placed under the ball and impressed by means of

¹ Described by H. S. and J. S. G. Primrose, *Proceedings of the Institution of Mechanical Engineers*, 1920, November, p. 942.

various loads in the usual way. The depths registered on the dial indicated the compression of the holder, since the steel clamp was clear of the specimen being impressed.

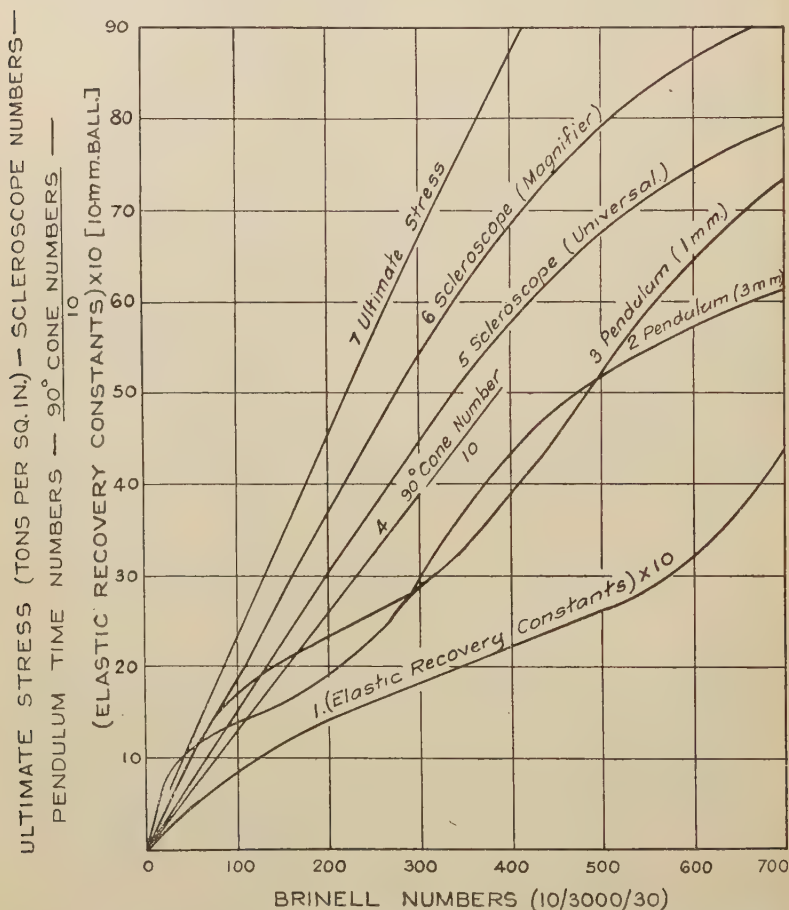


FIG. 2.—Average Curves obtained in Present Research by plotting Brinell Numbers (10/3000/30) against ultimate stresses, scleroscope numbers, Herbert pendulum time numbers, 90° cone numbers, and elastic recovery constants.

The elastic recovery of the ball-holder was found to be 0.01 mm. at 500 kg., 0.0175 mm. at 1000 kg., 0.035 mm. at 2000 kg., 0.0475 mm. at 3000 kg., 0.06 mm. at 4000 kg., and 0.07 mm. at 5000 kg.

Table III. contains some representative results showing the elastic recovery of certain materials on releasing the load

TABLE III.—*Elastic Recovery of Certain Materials on Releasing the Load in the Brinell Test (10-mm. Ball), using Amsler Depth Indicator.*

1.	2.	3.	4.	5.	6.
Load Applied. Kg.	Indicated Depth.		Elastic Recovery. (Col. 2 — Col. 3.)	Elastic Recovery, Corrected for Recovery of Ball-Holder.	Elastic Recovery (Corrected) (diam. of impression) × (depth of impression)
	Load On. Mm.	Load Off. Mm.			
<i>Annealed Mild Steel.</i>					
1000	0.36	0.27	0.09	0.07	0.81
1500	0.48	0.38	0.10	0.08	0.75
2000	0.62	0.49	0.13	0.09	0.82
2500	0.76	0.61	0.15	0.11	0.92
3000	0.89	0.73	0.16	0.12	0.82
4000	1.28	1.07	0.21	0.14	0.87
5000	1.48	1.24	0.24	0.17	0.90
Average, i.e. "Elastic Recovery Constant," 0.84					
<i>Grey Cast Iron.</i>					
250	0.08	0.03	0.05	0.04	1.33
500	0.14	0.07	0.07	0.06	1.50
750	0.19	0.11	0.08	0.07	1.33
1000	0.24	0.14	0.10	0.08	1.44
1500	0.34	0.20	0.14	0.11	1.57
2000	0.42	0.27	0.15	0.11	1.38
3000	0.59	0.39	0.20	0.15	1.48
4000	0.75	0.53	0.22	0.16	1.38
5000	0.91	0.66	0.25	0.18	1.41
Average, i.e. "Elastic Recovery Constant," 1.42					
<i>Hardened File Steel.</i>					
500	0.10	0.01	0.09	0.08	4.8
1000	0.15	0.02	0.13	0.11	5.7
1500	0.19	0.02	0.17	0.14	5.6
2000	0.24	0.04	0.20	0.17	5.8
3000	0.32	0.07	0.25	0.20	4.9
4000	0.40	0.09	0.31	0.25	5.3
5000	0.48	0.12	0.36	0.29	5.2
Average, i.e. "Elastic Recovery Constant," 5.3					

(column 4). In column 5 the results have been corrected for the elastic recovery of the ball-holder. The corrected results,

consequently, represent the recovery of the material under test plus that of the 10-mm. ball. The amount of recovery of the latter is presumably a function of, and increases with, the Brinell hardness of the material tested.

7. *Elastic Recovery Constants for Certain Materials.*

It will be seen that the "elastic recovery, corrected for recovery of ball-holder" results, in column 5, Table III., increase with increasing size of impression in a given material. If, however, each be multiplied by the diameter and divided by the depth of the impression concerned (as in the case of flattening), a *constant value is obtained for a given material*, within the limits of experimental error, as shown by the results in column 6 of Table III. The average elastic recovery constants of various annealed and tempered steels when plotted against their respective Brinell numbers give Curve 1 in Fig. 2. As in the case of flattening, however, cold-hammered materials lie somewhat above the average curve, while black vulcanite is far above, having an elastic recovery constant of 4.4 with a Brinell value of 20.

It will be noted that no allowance has been made for the elastic recovery of the 10-mm. ball in the above results, but this must have a small influence in the case of soft materials and a large one in the case of hard materials. The permanent deformation of the ball, as measured by Hadfield¹ and Batson² must also influence results obtained on materials above about 500 Brinell.

8. *Brinell Measurements with the Amsler Depth Indicator.*

The Amsler depth indicator measures the depth between the original surface and the bottom of the impression. Consequently, its indications cannot be converted directly into Brinell hardness numbers comparable with those obtained from diameter measurements, if sinking-in or piling-up or flattening occur, since differences of ± 30 per cent. may be recorded. The same factors

¹ Hadfield, *Proceedings of the Institution of Mechanical Engineers*, 1918, November, p. 586.

² Batson, *Proceedings of the Institution of Mechanical Engineers*, 1923, April, p. 420.

influence the Rockwell and other hardness testers which measure depths in a similar manner.

In the case of annealed and tempered steels, however, it has been shown in Table II. that the piling-up is approximately constant at 10 per cent., and the amount of elastic recovery increases progressively with the hardness. Consequently, a graph or table showing the relationship between depth indicator readings under a 3000-kg. load, and Brinell numbers obtained by measuring the diameters of the impressions produced, will give a reliable conversion for most *annealed and tempered steels*, well within the accuracy of the instrument.

9. *The Correlation of Brinell and Scleroscope Tests.*

One factor which must be taken into account when comparing Brinell and scleroscope results is that the angles of impression of the indents formed in a given material only correspond when a certain P/D^2 ratio is used in the Brinell test. Moreover, if they correspond on a given material, the tendency will be for them not to correspond on softer or harder materials, where the angles of impression will be greater or smaller. Furthermore, Genders¹ has pointed out that the noses of magnifier hammers vary considerably in contour in different hammers. In practice, however, a neglect of the above factor only results in discrepancies of the order of two or three scleroscope units.

A second factor which has to be taken into account when comparing Brinell and scleroscope results depends on the elastic properties of the material under test. Curves 5 and 6 in Fig. 2 show the average curves obtained by plotting scleroscope hardness numbers (universal and magnifier hammers²) of a number of materials against their Brinell numbers (10/3000/30).

It was observed, however, that those materials which had higher than average elastic recovery constants had correspondingly higher than average scleroscope hardnesses. In fact, on plotting scleroscope hardnesses against the corresponding elastic recovery

¹ Genders, *Journal of the Institute of Metals*, 1922, No. 1, p. 445.

² The "universal" and "magnifier" hammers used gave readings of 10.5 and 16.0 respectively on the 11.0-hard standard supplied, and 95 and 108 on the 100-hard standard.

constants, the results lay close to a smooth curve. (Red vulcanite was off the curve owing to its very low resistance to the deformation part of the scleroscope test, while black vulcanite happened to fall on the curve.)

Armco iron and mild steel, however, still lay off the curve. Consequently, there is a third factor which has to be taken into account in comparing the two tests, and which is related to the observation made by Edwards¹ "that tin, cadmium, zinc, and iron . . . were more resistant to penetration when tested by impact than if tested by the Brinell method."

The fact that Armco iron and mild steel (and probably zinc and tin, although the method of testing is not sufficiently accurate for these soft metals) did not fall on the average curve is in accordance with the above observation.

10. *The Correlation of Brinell and Herbert Pendulum Time Tests.*

In the first place, the 4-kg. and 1-mm. ball pendulum has a P/D^2 ratio of 4, and consequently, if used for making Brinell impressions, gives results only strictly comparable with 10-mm. ball Brinell tests, under a 400-kg. load. Similarly, the 4-kg. and 3-mm. ball pendulum results are only comparable with 10-mm. ball Brinell tests, using a 44.4-kg. load. As in the scleroscope test, however, the influence of this factor is almost within the limits of experimental error.

The average curves obtained by plotting pendulum time tests against Brinell numbers are shown by Curves 2 and 3 in Fig. 2. It was found, however, that those materials which had higher than average elastic recovery constants had higher than average pendulum time values (the pendulum time value for vulcanite was a long way above the average curve). This indicates that the pendulum time test is, like the scleroscope, dependent to a considerable extent on the elastic properties of the material under test.

Herbert,² and Benedicks and Christiansen,³ express the Brinell-

¹ Edwards, *Proceedings of the Institution of Mechanical Engineers*, 1918, October, p. 553.

² Herbert, *Proceedings of the Institution of Mechanical Engineers*, 1923, April, p. 457.

³ Benedicks and Christiansen, *Journal of the Iron and Steel Institute*, 1924, No. II. p. 219.

pendulum relationship by means of formulæ which are in approximate agreement with Curves 2 and 3 in Fig. 2.

If 1-mm. ball results are plotted against 3-mm. ball pendulum time results, the curve obtained is of the same general form as Curves 2 and 3 in Fig. 2.

11. 90° Steel Cone Tests.

A considerable number of tests was carried out, using 90° steel cones. The results were somewhat less consistent and accurate than those obtained using steel balls. Hankins'¹ observation that—

$$\text{Brinell number (10/3000/30)} = \frac{90^\circ \text{ cone number}}{1.3}$$

was confirmed and found to represent the average relationship. The use of graphite instead of vaseline was found to lower the 90° cone number by about 7 per cent.

The piling-up on cold-hammered copper was found to be 19 per cent., when using a 90° cone with vaseline, and probably about 1 per cent. less than this when using graphite. This specimen gave 27 per cent. piling-up under the ball test. On the same specimen the flattening due to elastic recovery was found to be a constant function of the depth (namely, 4 per cent.) for cone impressions of different sizes. The actual depth was measured by dropping a 1-mm. ball into the cone impression, taking spherometer readings on to the top of this ball, and then calculating the total depth.

12. Correlation of Brinell and Cone Tests.

It was found that the 90° cone tests were most nearly comparable with "90° angle of impression" ball tests (that is, 10-mm. impressions with a 10-mm. ball), expressed in the form $P/\pi r^2$. The results also indicated that materials which showed pronounced piling-up gave $P/\pi r^2$ cone values as much as 10 per cent. higher than the "90° angle of impression" $P/\pi r^2$ ball values, while when sinking-in occurred the $P/\pi r^2$ cone values were as much as 10 per cent. less.

¹ Hankins, *Proceedings of the Institution of Mechanical Engineers*, 1925, April, p. 620.

Similarly, a study of Hankins'¹ results indicates that his 120° cone tests are most nearly comparable with his $P/\pi r^2$ 10-mm. ball tests, when the diameters of the ball impressions are about 6.8 mm. (this corresponds with an "angle of impression" of 137°). Here again, however, the piling-up or sinking-in of the material under test presumably influences the results as above.

The same factors must also influence the correlation of diamond pyramid tester (136° across the facets) results² with Brinell results. A further factor to be considered when diamond indentors are used is that steel indentors are elastically compressed and deformed during a test, while the diamond indentors are not.³

13. Conclusions.

1. The sinking-in or piling-up of the material surrounding Brinell impressions have a constant value for a given material, irrespective of the size of the impression, if expressed as a percentage of the measured depth of impression.

2. In cast materials the sinking-in may be as much as 30 per cent. In annealed and tempered steels the piling-up is about 10 per cent. In cold-worked materials the piling-up may be as much as 30 per cent.

3. The value of n in $P = ad^n$ is related to, and varies with, the amount of sinking-in or piling-up.

4. Austenitic manganese steel does not obey Meyer's formula. For impressions above 6 mm. in diameter with a 10-mm. ball the value of n increases and the impressions sink in instead of piling up.

5. The depths (however measured) of Brinell impressions made with different loads on a given material (see Tables I. and III.) are not *exactly* proportional to the loads applied, as has sometimes been stated.

6. The Amsler depth indicator measures depths from the *original surface* to the bottom of the impression, and consequently can give differences of ± 30 per cent. if Brinell numbers are calculated from the indicated depths instead of from the diameters.

¹ Hankins, *loc. cit.*

² Smith and Sandland, *Journal of the Iron and Steel Institute*, 1925, No. I. p. 285.

³ This also applies to the use of diamond instead of steel balls in the various pendulum tests.

7. An average curve may, however, be constructed, by means of which Amsler depth readings may be converted into Brinell numbers which will give accurate results for annealed and tempered steels.

8. The flattening, measured on impressions of various sizes, gives a constant value on a given material, if multiplied by the diameter and divided by the depth of the impressions concerned. In general, the flattening increases with the Brinell hardness. Certain abnormally elastic materials, such as vulcanite, give, however, exceptionally high values, while cold-hammered materials give higher than average values.

9. In a similar way to the flattening, the elastic recovery of the material and Brinell ball, on releasing the applied load, gives a constant value for a given material if multiplied by the diameter and divided by the depth of the impressions concerned. The elastic recovery constants are generally proportional to the Brinell hardnesses, but, as before, certain materials give exceptionally high values for this property.

10. The scleroscope and pendulum time tests are to a considerable extent dependent on the elastic recovery properties of the material under test.

11. Cone tests are most nearly comparable with Brinell tests carried out with certain appropriate "angles of impression." The extent to which the material tested piles up or sinks in and recovers elastically has also to be taken into account when correlating the two tests. If diamond indentors are used, the elastic recovery of the diamond, compared with that of a steel indentor, has also to be taken into account.

The authors wish to acknowledge their indebtedness to Mr. E. G. Herbert, B.Sc., for kindly lending them one of his pendulum hardness testers; to Professor C. A. Edwards, D.Sc., for facilities for carrying out the work, and for his encouragement and interest; and to the Royal Society Committee for a Government Grant.

TWIN-LIKE CRYSTALS IN ANNEALED α -IRON.*

By HUGH O'NEILL, M.MET., M.Sc. (MANCHESTER).

ABSTRACT.

Certain small ferrite grains found embedded within the large crystals of a piece of decarburised steel plate have been examined metallographically. The specimen in question had been prepared by the method of straining and annealing, and a study of the form of the boundaries, pressure figures, and etch pits indicates that the small grains are twins. The results are consistent with the fluorite type of twinning.

ANNEALING twins are usually considered to be absent from aggregates of α -iron, though in 1926 the author ⁽¹⁾ suggested that certain twin-like "special bands" in recrystallised coarse ferrite ran straight through two grains *which were relatively twinned*. Since then Tamura ⁽²⁾ has observed "pseudo-twins" in annealed ferrite aggregates, and McKeehan ⁽³⁾ has proved the existence of twins in specially prepared single crystals of ingot iron. The present work describes twin-like grains observed in a ferrite crystal roughly $\frac{3}{8}$ in. square and $\frac{1}{8}$ in. thick.

The specimen in question was another portion of the material used in the earlier work, and consisted of a piece of coarse-grained high purity decarburised steel plate prepared by straining and annealing; it was presented to the author by Dr. Pfeil. It had been polished and etched, and then slightly strained in tension by the author in order to study slip-bands. Subsequently a fine grinding and polishing treatment had been given to remove the "grain uplift" resulting from deformation, and scratch hardness tests had then been carried out. On etching this new surface a curiously shaped grain (Fig. 3, Plate XLIV.) was noticed adjacent to one of the sclerometer scratches (visible to the right), and its appearance at once suggested a twin. The parent crystal was carefully

* Received February 4, 1928.

examined under the microscope and (besides a few smaller ones) altogether six grains were found which appeared to merit closer attention. Other coarse crystals in the specimen contained similar embedded grains, but these were not studied in detail, as the orientation of the parents could not be determined with sufficient accuracy.

"Pressure figures" were made with a loaded gramophone needle on many parts of the parent crystal, and the right-angled crosses obtained showed that it was exposing a cube (001) face, on which the arms of the crosses point to the corners of the cube.^(4, 5) With some difficulty pressure figures were also obtained on most of the tiny embedded grains, and they were all found to be similar to each other in form, consisting of two main collinear lobes, one of which was always subdivided (see Fig. 6). The lobes were found to lie along an axis parallel to an arm of the cube face "cross," that is, parallel to the cube face diagonal. Each of the grains was then photographed at a magnification of 120 diameters, the focusing and illumination being adjusted to show up the minute pressure figures as well as the grain boundaries—a condition sometimes difficult to secure. Fig. 1 has been prepared from careful tracings of these micrographs, the embedded grains being correctly orientated relative to each other and to the edges *FEDC* of the cube face of the parent crystal. Crystals 5 and 6 were just as far apart as Fig. 1 shows, but the other grains were widely separated. Parallel sclerometer scratches assisted in securing accurate orientation of the grains when preparing the figure from the micrographs.

When the work necessary to obtain Table I. had been carried out, the specimen was deeply etched, first in 4 per cent. alcoholic nitric acid, but later in copper ammonium chloride solution (1 to 12). The author finds the copper reagent much better for giving consistent results than nitric acid. With careful control of the time of etching, pits of a definite form have been obtained on other faces than that of the cube. Thus the embedded grains gave cavities appearing as isosceles triangles, which, by examination under high powers, were found to consist of inclined facets sloping down to three intersecting lines, as shown in Fig. 1. If the specimen were allowed to stand in the copper reagent for from 5 to 10 minutes instead of from 2 to 3 minutes, then the

triangles would appear to have been turned through 180° , but their general appearance was so different that experience soon enabled one to judge that the metal was over-etched. Ammonium

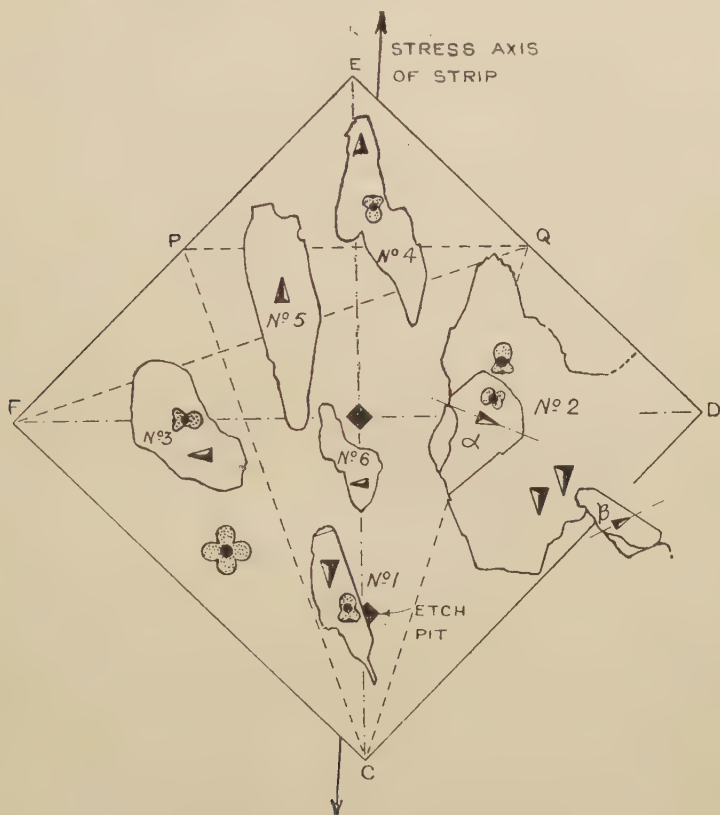


FIG. 1.—Magnification, 60 diameters.

persulphate (10 per cent.) was also found to be a reliable etching reagent, and is preferable to nitric acid.

The form and orientation of both pressure figures and etch pits are given in Fig. 1. Triangular and cube face pits may be seen as insets to micrograph Fig. 7 (Plate XLV.). The general impression to be gained from Fig. 1 is that the embedded grains have certain similarities. For one thing, their major dimension runs more or less in the direction of the axis of the specimen along

which tensile stress was applied during the preliminary cold-working operation. Furthermore, their boundaries in many places consist of nearly straight lines, which frequently run parallel to PC , QC , FQ , and perhaps PQ . These latter are traces on the cube face of (112) planes. Grain No. 2 is noteworthy in that it contains within it what appear to be two twinned areas marked α and β in Fig. 1. In Fig. 7 this same grain is shown after several polishings and deep etchings, and it was given a light polish just before being photographed. Only area α was visible when Fig. 6 was taken, but at a lower depth, as in Fig. 7, area β had come into view. The straight boundaries to these areas were inclined at about 55° to the cube face diagonal, and difficulty was found in producing etch pits within them. After many trials the structures shown in Fig. 8 were secured in area α , and similar ones in area β , by which time polishing had worn right through part of grain No. 2 so as to produce a cube-etching area at its centre. This is visible in the top right-hand corner of Fig. 8, and, like the cube surface in the lower left-hand corner, it is out of focus, as the surface of area α was at a higher level. The depression down the centre of the triangular pits of area α was inclined at about 60° to the straight boundary, and the imperfect pressure figure of this crystal was consistent with pits of this type. The order of ease of etching of the specimen was: cube face, faces of embedded grains, and, lastly, faces α and β . After further light polishing, area β was practically worn through, and it is evident that some of these embedded grains are of the nature of thin plates.

Grain No. 1 is the most suitable for purposes of measurement, and its sharp-pointed end is shown in Fig. 5. In Fig. 4 sclerometer scratches and pressure figures are photographed, the dark patch at the blunt end of the grain being due to unsuccessful attempts to indent it. Careful tracings were made of Figs. 3, 4, and 5, and Fig. 2a has been drawn from the measurements secured. Another micrograph (not reproduced) was used to assist in determining the position of the cube face diagonal AB , but an error of one or two degrees is scarcely avoidable in the solution of the pressure figures.

The angles at which the straight boundaries are inclined to one another and to the cube face diagonal are given in Table I.

The values suggest that the boundaries are the traces on the cube face of the (112) traces PAC , QBC , or $P'AE$, $Q'BE$, represented

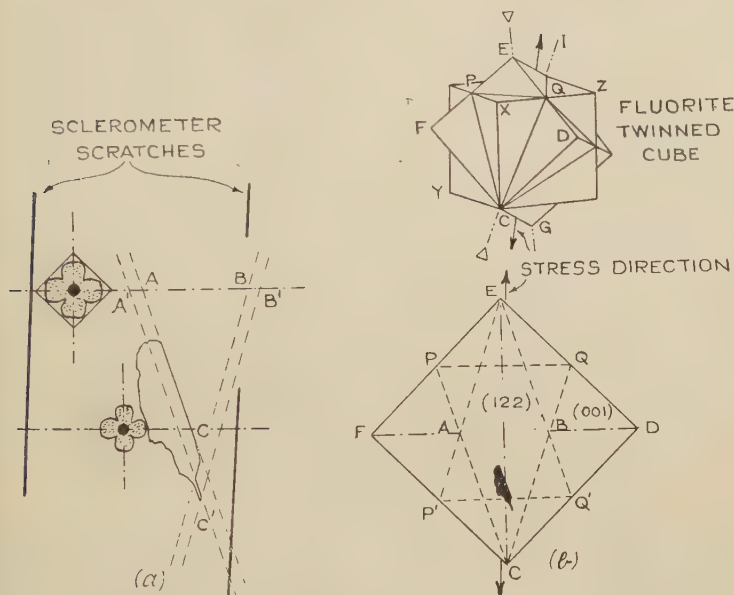


FIG. 2.

in Fig. 2b, and the appropriate theoretical angles are therefore given.

TABLE I.

Observed Angles of Intersection.		Theoretical Angles for Traces of (112) Planes.
Angle ACB , 35.5°	Angle $A'C'B'$, 34°	Angle ACB , $36^\circ 52'$
" CAB , 72°	" $C'A'B'$, 72°	" CAB , $71^\circ 34'$
" ABC , 72.5°	" $A'B'C'$, 74°	" ABC , $71^\circ 34'$

After deep etching the straight boundary AC was found to run through a perfect cubic etch pit, just as shown in Fig. 1, that is, parallel to a (112) trace. Furthermore, the blunt end of grain No. 1 developed a straight etching boundary perpendicular to the boundary AC , that is, parallel to the (112) trace FQ . These

results are considered to prove that within the limits of experimental error, *and considering the slightly strained condition of the specimen*, the straight boundaries are parallel to the traces of (112) planes. The second series of values is less likely to be as accurate as the first, owing to the very short boundary available for obtaining the direction $C'B'$. The two (112) planes involved contain a common trigonal axis (CI or EG , Fig. 2b) or (111) slip direction, which lies near to the direction of tensile stress.

Elsewhere ⁽¹⁾ the author has shown that deformation of a single crystal of ferrite may take place on (112) planes in the (111) direction, and Pfeil ⁽⁵⁾ has obtained similar results. Taylor and Elam, ⁽⁶⁾ on the other hand, found "columnar" slipping in the (111) direction, but not necessarily along (112) planes. The author inclines to the view that in such "columnar" movement the "columns" *may* be bounded by (112) planes, and McKeehan ⁽³⁾ has expressed a similar opinion. With movement in the (111) direction along (112) faces it has been shown to be possible to obtain mechanical twins on such planes by slip alone. ^(1, 7, 3) Subsequent annealing may then produce annealing twins in a manner similar to that suggested by Carpenter and Tamura, ⁽⁸⁾ and in the metal under consideration such twins will tend to be bounded by (112) planes. Since there are twelve (112) orientations, alternations between them may occur, and long straight twin boundaries would then be avoided.

The mechanism of α -iron favoured above has been shown by Millington and Thompson ⁽⁷⁾ to correspond, when twins are produced, to the fluorite type of twinning proposed for iron by Linck, and confirmed by Osmond and Cartaud ⁽⁴⁾ in the case of Neumann bands. In fluorite a (001) face $EDCF$ (Fig. 2b) of the parent cube lies in a (122) plane (PQC) of the twin cube. If the small embedded crystal under consideration is really such a twin it should give evidence of having (112) traces for its boundaries, and should be presenting a (122) face with a single axis of symmetry running parallel to the cube face diagonal (EC). The first of these conditions has been shown to be satisfied, and the pressure figure and etch pit evidence is consistent with the second. Its etch pits may even be considered to provide proof of the (122) plane, for since etch facets in iron are composed of cube faces, ⁽⁹⁾ then the etch pit on such a plane should resemble the three-

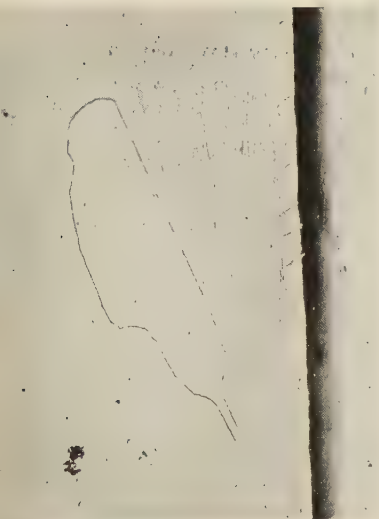


FIG. 3.— $\times 180$.



FIG. 4.— $\times 120$.



FIG. 5.— $\times 700$.



FIG. 6.— $\times 120$.

The above micrographs have been reduced to four-fifths linear in reproduction.

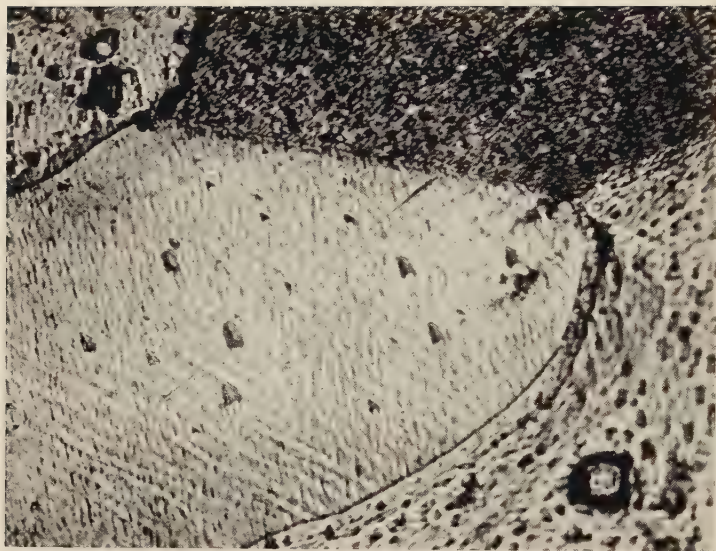


FIG. 8. — $\times 500$.

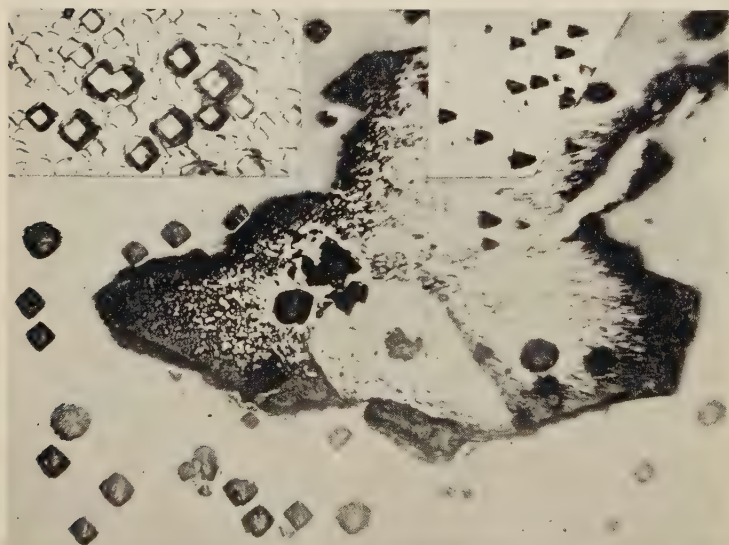


FIG. 7.— $\times 120$.

dimensional body $XPQC$ of Fig. 2b. Careful examination of the pits at high and low powers has shown that they are depressions of the required shape, and measurements on the camera screen gave an angle (ACB) of 38° . The author is therefore of the opinion that grain No. 1 is a twin of the large cube-faced crystal.

Granting this, there appears to be no reason why the other embedded grains should not also be twins. They have the required similarities, though twinning round more than one of the trigonal axes is required to explain the different orientations of Nos. 3 and 6 and No. 4. Grain No. 2 appears to contain twins of its own which may possibly be zones formed by the intersection of twin slabs orientated in two directions.

If it be conceded, then, that small twinned crystals are to be found embedded within the coarse grains of the decarburised steel which has been examined, three causes may be considered to account for their presence. The first possibility is that they are true annealing twins produced in the ordinary way by cold-work and recrystallisation. The second is that they are unabsorbed grains of the original fine-grained aggregate whose orientations were by chance relatively twinned to that of the large crystals which eventually grew round them. In support of this, both Tamura⁽²⁾ and McKeehan⁽³⁾ found that their ferrite twins were very stable and did not become absorbed after prolonged annealings below A_3 . The third possibility is that twins in α -iron may be associated with twinned γ -iron from which it has been produced.

It is not easy at present to rule out any of these possibilities, for the following reasons :

1. Tamura⁽²⁾ found "pseudo-twins" in grains of a mild steel from which carbide had been driven to the boundaries by slow cooling after annealing *above* A_3 .

2. McKeehan⁽³⁾ found twins after slowly cooling previously cold-worked ingot iron from 1400°C . in hydrogen.

3. Austin⁽¹⁰⁾ observed "columnarisation" of ferrite in steels decarburised in hydrogen and slowly cooled. One may notice some fairly straight-sided grains in Austin's decarburised ferrite.

4. Grains with straight boundaries may be observed in micrographs obtained by Edwards and Pfeil⁽¹¹⁾ of steel decarburised.

in hydrogen above A_3 and slowly cooled (see their Figs. 14 and 16, *loc. cit.*, Plate IX.).

5. The presence of twinned α -grains has been suspected by Hughes⁽¹²⁾ in electrolytic iron. Such iron generally contains dissolved hydrogen. Stead and Carpenter⁽¹³⁾ found that thin plates of this material develop large grains when heated to just above A_3 and cooled to below A_3 —conditions under which wrought iron and mild steel show no such grain growth.

The effect of gradient and decarburising conditions during annealing obviously must not be overlooked. Also items (1), (3), and (4) above must be considered in connection with the second possibility previously given, to which the objection may be made that unabsorbed grains would not have sufficiently straight boundaries.

The author believes that the small crystals which have been examined are annealing twins, because of their orientation relative to the direction of previously applied stress, and because their final annealing was below A_3 . Krivobok⁽¹⁴⁾ found that mechanical twins in ferrite recrystallise largely by extending their boundaries and becoming grains whose straight sides are related to the twin directions. The author's studies of the annealing of a strained ferrite crystal⁽¹⁵⁾ have shown that out of the hard "etch-bands" straight-sided grains grow in a direction related to that of slipping. Annealing at higher temperatures and for longer times is found to cause further growth in such a way that straight boundaries tend to be lost. This appears to be the reason why annealing twins would not readily be recognised in ferrite, and for the same reason it was held until recently that aluminium did not twin. In the latter metal straight-sided grains are found after recrystallisation, and twinning is now known to occur.

A point of practical importance arising from this study is the effect that such embedded twin-like grains will have upon the mechanical test values of "single" crystals of iron. If the latter have been prepared by the method of decarburising, straining, and annealing, then it seems that they may contain internal twin-like grains. In such a case the tensile values would probably tend to differ very slightly from those of a *cast* and annealed single crystal.

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ANNUAL DINNER.

THE Annual Dinner of the Institute was held in the Grand Hall, Connaught Rooms, on Thursday, May 3, 1928, under the Chairmanship of Mr. BENJAMIN TALBOT, President. An unusually large number of members and guests were present, among them being His Excellency the Marqués de Merry del Val, Spanish Ambassador; Mr. Charles M. Schwab (Bessemer Medallist), President of the American Iron and Steel Institute; the Rt. Hon. Viscount Furness; the Rt. Hon. John Hodge; Mr. E. F. C. Trench, C.B.E., President of the Institution of Civil Engineers; Geheimrat Professor F. Wüst; Mr. A. de Churruca and Mr. Luis Barreiro, respectively President and Hon. Secretary of the Bilbao Reception Committee; Mr. Ramon Quijano; Dr. W. Rosenhain, F.R.S., President of the Institute of Metals; Sir Joseph Petavel, K.B.E., Director, National Physical Laboratory; Sir William Larke, K.B.E., Director, National Federation of Iron and Steel Manufacturers; Mr. H. Spannagel; Mr. P. Gouge; Mr. R. E. Palmer, President, Institution of Mining and Metallurgy; Mr. R. W. Allan, President, Institution of Mechanical Engineers.

On the proposal of the President the loyal toasts were received with the usual honours.

Mr. F. W. HARBORD, C.B.E. (Immediate Past-President), in proposing the toast of "The Guests," said: We always look forward to this occasion as giving us an opportunity to entertain our guests, and to-night we are fortunate in being honoured by the presence of many distinguished gentlemen. We have with us His Excellency the Marqués de Merry del Val, and Mr. Alfonso de Churruca, whose names are coupled with this toast. His Excellency the Marqués has for the last fifteen years represented his country at the Court of St. James's and has devoted his great ability to fostering those cordial relations which have so long existed between our two countries. We thank him for the way in which he has consolidated and cemented these bonds of friend-

ship. Mr. de Churruca is the Chairman, as you know, of the Bilbao Reception Committee, where we are to hold our Autumn Meeting, and he and Mr. Barreiro have come over especially from Spain to attend our meetings this week. There is another of their compatriots present, Mr. Quijano, who is known to many of us here to-night. Thirty-two years ago we held an Autumn Meeting in Bilbao, and those who, like myself, were privileged to be present on that occasion, if they are able to go there this year, will see very great changes. The port of Bilbao has been always noted as a centre of mining and metallurgy, but during the last thirty years great developments have taken place, not only in the mining and metallurgical industries, but in other industries in which Spain is interested. The Prime Minister, General Primo de Rivera, has graciously extended his patronage to our meeting, and the only thing we fear is that we may be overwhelmed with their hospitality. Recently Spain has been celebrating the centenary of one of the world's great artists, Goya, and those who are able to go to Spain may hope to see the wonderful collection of his pictures in the Prado Gallery, together with the masterpieces of Velasquez and Murillo. Another guest that we have with us to-night is Mr. Charles Schwab, President of the Bethlehem Steel Corporation of America. Mr. Schwab, as you know, has to-day been presented by this Institute with the Bessemer Medal, the highest award we have in our power to offer, for his great services in the development of the iron and steel industry not only in America but in the whole world. He is one of that rare type of men in whom is combined financial and business ability with sound technical knowledge. Among our other guests we also welcome here to-night friends from Germany and from France. Professor Wüst is with us, and we are delighted to see him. Among our French friends are Mr. Gouge and Mr. Monfort, and we are very pleased to have these gentlemen with us to-night. We are also very glad to see our old friend Mr. Hodge once again. Mr. Hodge is going to speak after me, and therefore it behoves me to be very careful of what I say. At best I can only refer either to his past or to his future. His past is well known to you all; his future is too uncertain, and I do not care to prophesy about it. We have with us also to-night five guests who, on the invitation of your President, represent the operators in our great industry. They come from five different

iron and steel manufacturing districts, and each one represents the skilled men of his district. I need not say to these gentlemen how delighted we are to see them here to-night, and I wish to express the hope that in future years these members of our great industry will be always represented at our Annual Dinner.

The MARQUÉS DE MERRY DEL VAL (Spanish Ambassador), in responding, said: Mr. President, My Lords and Gentlemen, To our hosts of this evening my fellow-guests bid me offer cordial thanks for the hospitality, substantial, as we might well expect of the so-called heavy industries, and at the same time distinguished by the good taste and amplitude which we associate with the name of the Iron and Steel Institute. We thank Mr. Harbord also for the flattering words he has addressed to us, which we will take away as a pleasant memory of this evening when we leave this hall.

Those who from the outside look up to and upon the great iron and steel industry represented by your Institute cannot but feel a sentiment of admiration, I might almost say of veneration, for one of the greatest trades of mankind. You may go back in the history of the world, through the pages of the Bible or any other annals of ancient times, and ever will you find that in our civilisation—a civilisation which has risen to the greatest heights man has ever known, and which has before it a future we cannot yet fathom—man has lived under the rule of iron and steel. Other peoples there have been who have prospered, flourished, and passed away using stone and bronze for their implements, such as those which once flourished in Egypt, and even at first in Rome, and again across the Atlantic amongst the Mayas and such-like peoples, but the great triumph of man came with the knowledge and use of iron and steel. It has been said that we live in the age of iron—with a political intention, of course, but the truth is that our races have lived in an iron age. You will find evidence of this on every hand in the very names you bear, be you Latins or be you Teutons—the smith has always been honoured amongst you. Again, in the Basque language, you will find that amongst that race, which has worked on iron since the days of Tubal Cain and claims to speak his language whenever the opportunity occurs, there is a reference to a forging industry by some stream in the Basque valleys reaching far back into prehistoric times. What has

been Great Britain's part in this great work? In the eighteenth century you already began to devise new methods and improvements, and then your great Stephenson appeared, carrying to perfection Watt's application of steam. Again, name after name, Nasmyth, Armstrong, and others appear, and at last you have raised this great industry to the state of perfection as we now know it and have made of it the very life of our world of to-day. But that is not all. Britain has carried this industry into other lands. In Spain and Belgium, Austria and other countries, we find a memory of those great iron-masters who spread their knowledge and your work throughout the whole of Europe, and we are all indebted in some measure to Great Britain for the present prosperity of metallurgy in civilised nations. But there is still another aspect of your activity. You have been not only a link through your industry, but in the great Iron and Steel Institute you have carried with you the name and fame of British ironworkers, and you have had the sympathy which accompanies you wherever you go. For the first time I went to the town of Bilbao, the centre of Spanish ironworkers, in 1900, and the echoes of your visit of 1896 were still floating in the streets of that town. They had not forgotten you, and I assure you they will be delighted to welcome you again in as courteous and as warm a manner as they did thirty-two years ago. I am not unaware of the existence of a certain amount of grievance in this country against Spain's commercial policy of the day. Sheffield particularly has been of late fully vocal, so that we may well say here that steel for Spain has been particularly sharp and pointed, reminding me of our old Toledo blades of which the temper is still what it was a thousand years ago. You are now going to visit Spain, and I ask you, Why not take the opportunity and make of your visit a diplomatic mission? My Government is a very human Government. I give no undertaking, but of one thing I am sure: they will hear you and hear you with sympathy, and you will know that more is done over a glass of good Spanish wine than by any amount of correspondence. Your guests to-night, amongst whom we have the satisfaction and honour of seeing men like Mr. Schwab, are grateful to you for your entertainment, and it is in their name and not in my own only that I speak now. We are particularly full of gratitude to Mr. Harbord for his reception of us, and I as

a Spaniard am especially so for the way in which he has so gracefully commemorated our great painter Francisco de Goya, whose centenary we are celebrating at this moment in Madrid. I have referred to the presence to-night of a great United States citizen, and everybody who loves peace in the world must be pleased to see an authorised representative of that country amongst you, because we know that your friendship with him and his people makes for the good of us all and for the peace of the world.

Mr. ALFONSO DE CHURRUCA (President of the Executive Committee for the Reception of the Members at Bilbao), speaking in Spanish, said : It would have been my desire to address you in English, but in view of my inability to do so, you will be good enough to allow me to say a few words in my own language in order to express, publicly, to the Council of the Iron and Steel Institute my gratitude for the little-deserved honour which they have shown me in asking me to undertake the Presidency of the Executive Committee for the forthcoming meeting at Bilbao. At the same time, I would like to transmit to you a cordial greeting on behalf of the Spanish members of this Institute.

The speech of our illustrious ambassador, the Marqués de Merry del Val, exempts me from troubling you with many words, for he has expressed, better than anyone else could do it, the eagerness with which we in Spain are looking forward to your visit; and the honour which you have shown us by accepting our invitation. It only remains for me to add that the Executive Committee of the Autumn Meeting is pursuing its work with the greatest interest in order to render your stay in Spain as agreeable as possible, so that we may experience a real pride in being able to show you a nation which has made great advances as the results of its own industry, of the type which it is peculiarly fitted by nature to carry out.

Mr. CHARLES M. SCHWAB (President of the American Iron and Steel Institute), in proposing the toast of "The Iron and Steel Industries," said : Mr. President, Your Excellencies, My Lords, Ladies and Gentlemen—I am glad I have got through that part of my speech. In America, when I speak to the Iron and Steel Institute I am very apt to begin "Well, boys." I was so pleased at

the speech of His Excellency the Spanish Ambassador in thanking this Institute for the kindly welcome the members had given their guests, because he did it in such a faultless and fine manner that I was doubtful about the necessity of doing more than adding my complete commendation of the delightful answer he made to the President. With reference to the speech of the other Spanish gentleman, I was also delighted, because I have made many speeches in my life, and I have often wished that many of them had been made in Spanish. When I had the invitation of your President to come to London to receive the Bessemer Medal, of course there was nothing in the world that would have stood in my way in coming here to receive that honour at your hands as being the climax and culmination of fifty years' endeavour in iron and steel. It is not the money that I have made nor the position I have obtained in steel that has brought me real pleasure, but it has been the privilege of the friendship of those with whom I have been associated for fifty long years that has given a good deal of pleasure and joy of heart to the old American steel-master. When I received this Medal it was not in my thoughts that I would be obliged to make a speech in London. You know, boys, that I am just a workman. I noted some of the workmen from Sheffield here this evening, and when I saw them I felt at once that I was in my own class. I always regret having to make a speech, because when I do so I make three speeches: I make a speech when I am coming to the banquet, elaborating things, as I might say, and then I make a speech at the banquet, but the real speech is the one I make in the carriage going home.

I told a story at a little dinner last night. At one time I was in London and met a man who was decorated with medals from one shoulder to the other. I said to myself, "Now, there is a distinguished man," and I asked him why he had so many medals of distinction, and he said, "The first large one on my left I got by mistake, and I got all the others because I got the first." Well, my friends, I feel that way about this Medal that you have bestowed upon me. It will be a treasure in my household. But if I do not deserve it as a manufacturer of steel, I claim to deserve it as a real patriotic American and English citizen for the development of civilisation in this great world; and so, my friends, I shall carry back with me upon the ship this valued treasure which I owe

to you, and for which I have given due thanks to your learned Council who have presented it to me. But I carry back something of deeper significance than the Medal itself, and that is the appreciation of your friendship and our long years of association together. I have had much to do with your country and your people. I do not look so old as some of you or some of the ladies might think. I am one of the few men in this room—I doubt if there are a dozen—who knew the great Henry Bessemer; I am one of the men who remember him in his early days. Of course that marks my status in this business. I started in the steel business in 1879, nearly fifty years ago. I remember when the United States thought they had reached the maximum of their tonnage when they produced 700,000 tons of steel a year; I was there in 1910 when they produced 8,000,000 tons of steel in a year, and I was still there this year when they were producing 50,000,000 tons of steel.

I am an optimist. I believe that the development of the world in iron and steel is going on and on, and that Great Britain with her traditions of iron and steel is going to be one of the foremost nations of the world in the development of this great basic industry. I do not say that in idle talk. We Americans are given to boasting. There has not been a great process in iron and steel that has marked America or any other country's development that did not have its origin here in Great Britain.

Bessemer led the way, and that revolutionised the industry. I know exactly how we were taught to make steel in America, but it originated in Great Britain. Then came the development of the open-hearth, the Siemens open-hearth, and others, all of which were originally developed in Great Britain. Great Britain is the mother-house of the development of steel industries. We in the United States with our great natural resources and tremendous home demands for steel, it is true, have given refinement and development to the processes which were originated here, and between the two of us we have developed the industry in this world, and it will be so in the future. We will develop this industry. This mother-house has not started as yet as she will start. Mother necessity will make you start to develop your own iron and steel industries on lines which we in America, who think chiefly of money-making to-day, will not develop as you will. We are very

friendly to you in Great Britain. We are not competitors with you in business. There are very few markets in which we become competitors, except perhaps South America and other places that cut no figure. Only 8 per cent. of the American steel is used in countries other than America : it is the home market that has made America rich and prosperous in steel, and you must have your own market in your own country to carry your overhead and other expenses while you develop abroad. I am a citizen of America, and I do not interfere with this country, and I am not a dictator, but I would say to you as iron and steel men, Protect your industries.

There is no necessity for Europe to ship three, four, or five million tons of steel into Great Britain ; it ought to be manufactured in Great Britain. It takes 4 or 5 tons of coal for every ton of steel, and if you make four million tons it means that you are buying so many million tons of coal more a year. You would have transportation and everything else, and would get money and profits to enable you to go into foreign countries and build up your business. England has something that no other country in the world has, and that is its traditional ability in managing shipping, in your command of the seas which will give you the command of every market in the world at even prices, because people know that when they buy products from Great Britain they are going to have them shipped promptly without any delay. No other country in the world has these advantages but you people in Great Britain. Boys, do not be discouraged. Jump to it and go on with it. You will find friends in the Presidents of the American Iron and Steel Institute, and you will find all over America friends in connection with the development of your business.

I am going to tell a story at this point. In America Mr. Carnegie was a very rich man, a medallist, and I was reputed to be a rich man. At one time we were travelling in our car together to a university in Pennsylvania to dedicate some buildings. One was a great library—which Mr. Carnegie had a penchant for giving—and the other was an auditorium. We had these two buildings to dedicate one night. We went up together in my car—Mr. Carnegie was too poor to own a car, and he used to use my car whenever he liked. He would send me a note to say when he

wanted it, and mention what a good thing it was to have rich friends. On the journey we dressed on the car before we got to the college. My valet was there, and he said, "I cannot work for you any longer—I will not work for you." I said, "Well, what is wrong?" He said, "You two fellows came up here to give away two million dollars each, and you have only one measly collar button between you!" Whatever you may think, do not be discouraged by the fact that you have but a single collar button between you to-day; go into it with spirit and energy and with the philosophy of the old steel-master, who will tell you his philosophy in life, and you will be surprised at the results that will be obtained. Of course you will lose sometimes, but who is there that does not lose at some time or other?

Up at the works at Bethlehem I have a great military band, 120 boys strong, and I am proud of them. I take them to New York every year for a concert in the park, and the people come in thousands to hear them. They can play a horn as only a Pennsylvanian Dutchman can. I gave them a dinner—in those days we did not have prohibition, and so we were very jolly. We enjoyed that dinner as only a Pennsylvanian Dutchman can when he does not have to pay for it. After the dinner, when we were going back in the train, the old fellow that beat the drum was in profound contemplation of his good dinner, when the conductor came along and said, "Your ticket, please." He fumbled in one pocket and the other and said, "I believe I have lost that ticket." "Oh no," said the conductor, "you could not have lost the ticket—that is impossible." "Oh, hell, could I not!" he said—"I lost my bass drum to-day!"

Well, you are going to have prosperity. I am an optimist, and always have been. I have built mills and industries in America in the fifty years of my existence there; I have gone on and on, and I have never built an industry that proved to be of sufficient size to meet the demands of the ages that followed. Emil Ludwig in New York the other day asked the big business men of New York a question. He said, "I should like to know whether a big business man ever reaches his objective, and if he does reach it, how he feels." Mr. Kahn told me to answer him. I said, "In the first place, Mr. Ludwig, if he was a big man he would never try to reach his objective: it is always ahead of him. No matter

what his age or experience, a big man has always something ahead of him, and no big man ever reaches his objective."

The English nation is the squarest nation on the face of the earth. In trying times, when I and other men in America stood for more liberal terms than you received in connection with the debt, you stood up like men, and you have acted the part of men. You have the tradition of a nation that is honest, and God knows that no such nation can go down to industrial failure any more than they can descend to an ignoble act. That is my feeling for your great country and your great society.

I have brought with me the invitation of the American Iron and Steel Institute inviting you to America, and I renew the invitation to each member of your Iron and Steel Institute, and I say to you that there is nothing we have in America in the way of manufacture and costs that we are not ready to give you and co-operate with you if it will better your condition here.

It is easy to give advice. I am called the Father of the Steel Corporation in the United States because I was the first to see the economic advantage of great business. If I were a dictator of the iron and steel industry in Great Britain, I would form all your companies into three or four great companies, and put them forward with all the economies of management that would come from that, and then I would say, Use your influence and great position in the world to do for your Government what they ought to do for you. That is my position. Some may think that perhaps that is against American industry, and that I am the President of the American Institute ; but it does not matter much what they think about it. I have said what I have to say because I believe it is right. There is the philosophy—the philosophy of the old steel-masters—which is worth having at the depressed times of your industry, and that is the philosophy of happiness and good-nature in business. I am sentimental in business. Foreigners say that Americans are not sentimental. But we are sentimental, not artistically or musically, because we are too young for that, but we are sentimental in business and in industry, and we find our chief joy in doing what is worth doing well. The aristocracy of to-day is the aristocracy of men who do something for their fellow-men. I said to your good working-men this evening that from my long experience in life it is my opinion that the average

standard of morality amongst the good, straightforward workmen in this country and the United States is higher than any other thing in those two countries.

I have learned many lessons from these men. When I was a young man in charge of the Homestead Steelworks I was going round with Mr. Carnegie. I knew all the tricks of the trade, and probably some of them were learned from me at Homestead. Mr. Carnegie came up, and standing at one of the great open-hearth pits there were two fellows having a good loaf. I said, "That looks bad," and I said to them, "What are you doing down there?" One of them looked up and said, "Who are you?" I said, "I am the manager." He said, "Well, you have a damn good job—take care of it!"

I was telling a story at a dinner the other night that when I was in Bethlehem in 1900 and was requiring money I was told that I could have half a million. I said, "I have to have a lot more than that. George Baker in New York did not know me, and he gave me more than that"; and the other fellow said, "That is the reason he gave it to you!"

I have had a good time: I have enjoyed every year of my life. I look back on the days of the old masters, including Windsor Richards—very happy days!—and the recollection is a cherished memory. I have not many more years to spend in the world in this industry, but when I go I shall be remembered by friends throughout America, and I hope I shall have the same kind of sentiment here in Great Britain.

I thank you for this opportunity of appearing before you. I thank you sincerely for the honours you have bestowed upon me. I thank you for listening to this drivel in American patois—but a good many of you seem to understand it. I thank you for the hearty reception, and for the kindly spirit that you have manifested in your every action towards this American and his friends in the United States. I appreciate it beyond description, and I will take back to the Iron and Steel Institute, which meets in New York on the 25th of this month, very happy recollections. I have been trying to think of something for my Presidential Address, and I am going to talk of the British iron and steel industry, and their courtesy and kindly feelings towards America, and cement the relations between the two countries more strongly.

We are the children of Great Britain. We have grown up, and we are asserting some of the independence of our forbears, but we are still children of Great Britain bound to your great country, and whatever individuals may say, take it from me, that the average American citizen worth while loves Great Britain, admires Great Britain, and none more so than your humble servant. God bless you all.

The Right Hon. JOHN HODGE, in proposing the toast of "The Iron and Steel Institute," said: I feel myself in a most embarrassing position. I do not know that I have ever listened to a greater after-dinner oration than that of Mr. Schwab. He started so modestly that the good things he said must have been thought of after he got away from me. I feel like a lamb in a den of lions here—all manufacturers, and I am the poor official of a Trade Union! For over forty years I have had my hands in these gentlemen's pockets, and they rather liked it.

The toast that I have to submit to you to-night is that of the Iron and Steel Institute, and that reminds me also of a story of an old Scots farmer, who every night had family worship, and his prayer always ended like this, "Finally, O Lord, pray give us a good conceit of ourselves," and that is the position I feel in to-night—I am entitled to feel a bit conceited in being selected to propose this toast, and I am also conceited in the belief that there is no one present better fitted to propose it than I am. I think another reason is this: I was a puddler in my young days, and when I was eight years old I was a furnaceman. I told a Staffordshire audience that fact two or three years ago and they laughed uproariously, and I told them that I was heating bands for the bundler in the mill, and if that is not furnacing, I do not know what is. It so happened that it was the school holidays, and I went into the works and carried on, but when the holidays were over my mother said to me, "Back to school!" and back to school I had to go; but ever since that time I have been connected more or less with the steel trade. The Steel Company of Scotland was really the mother works so far as the Siemens process was concerned in this country, and they have sent workmen out all over the world for the purpose of teaching others. What developments we have seen in the forty years or more which have passed

since then! Your President is one of those who have been endeavouring to develop the industry, and he is still at it, with new methods, and from all accounts successful methods, and I claim that without the whole-hearted co-operation of the workmen that success could not have been obtained.

Another development I think we have to thank the President for is that for the first time in the history of this Institute he has made a departure in asking several workmen to take part in your deliberations to-day and be your guests to-night. It is not good for the Institute to keep all the knowledge to themselves. It is close on forty years since I approached the Employers' Association for a conference for the purpose of considering the question of technical education, and it took a great deal of trouble and persistency before that conference took place. With the modesty which is natural to a Scotsman, I fancy I made a most excellent speech, a practical and convincing speech; but it did not convince the then Chairman of the Employers' Association, who was a hard-headed Yorkshireman. If you want anything in this world worse than a Scotsman, more stupid than a Scotsman, more stubborn than a Scotsman, get a Yorkshireman. When I had finished my carefully prepared oration, a speech of much thought and great consideration and practical knowledge, he got up and said, "We have listened to your very excellent oration, Mr. Hodge, but I want to tell you this, and tell it to you plainly and most emphatically: we are not an educational Association, but an Association for the regulation of wages and the conditions of labour." I pointed out on that occasion that a great deal was wasted because the workers among other things did not know the principles of combustion. That is the kind of thing I wanted to correct. You know what a conservative lot the employers were—I do not know that you are a great deal better to-day. I have been preaching Mr. Schwab's policy for a good many years—the protection of industry—and these people here, Mr. Schwab, cannot agree amongst themselves. I am glad that I have such a stalwart superior in you, because surely if they won't believe me they will believe you. I think we all agree—I know that you will agree—that the Iron and Steel Institute has done a great deal for the development of the industry. It has been world-wide in its application. It has not been narrow and insular, which is

evidenced from the fact that we have Mr. Schwab here, and from the fact that you are going to Spain next September—and I am wondering if I am going to get an invitation. I hope Mr. Talbot's departure in inviting selected workmen to attend at least one of your meetings per annum will be followed by his successor in office. As a matter of fact, next year I dare say there will be great competition for the honour of coming. I can only say in conclusion how much I feel honoured in having the privilege of proposing this toast, and of wishing continued success and prosperity to the Iron and Steel Institute.

The PRESIDENT: Before replying to the toasts of Mr. Charles M. Schwab and Mr. John Hodge of "Success to the Industry" and "The Iron and Steel Institute," I must first of all thank His Excellency the Spanish Ambassador and Messrs. de Churrueta and Barreiro for their presence here, and for having so cordially endorsed the invitation to visit their country next September. We are looking forward to a very useful and enjoyable meeting at Bilbao, and feel greatly indebted to His Excellency for coming here this evening and intimating to us in such eloquent language what an interesting time we are to have.

We are also deeply indebted to Mr. Schwab, who has thought it sufficiently important specially to cross the ocean to honour us with his presence at this meeting. We thank him heartily for his great speech, and are sorry that his stay in this country will be of only three or four days' duration.

A fortnight ago a number of us were here in this hall, and the financial position of the British iron and steel industry was referred to; I am afraid some of us were not particularly happy, as we had to think of balance-sheets. At our meetings this week our attention is confined to the scientific and technical aspects of the industry, and, in my opinion, in reviewing these we have the right to feel satisfied, although so far we are without full consolation for our difficulties on the financial side. I consider that the scientific condition of our industry here is second to none, and in some departments, such as alloys and special steels, it is probable that we lead the world. The British output represents about 10 per cent. of the world's production of steel ingots, and our most captious critics must admit that with a make of about 10 million

tons out of a world total of 100 million tons our contribution to the scientific and technical work in the industry is still greatly in excess of our proportion of the world's tonnage output. The efficiency in the scientific and technical sections of our industry shows that the leaders are not deficient in the knowledge necessary for its progress, and that the commercial and financial difficulties must be due to the peculiar conditions with which they have to contend as compared with their foreign competitors. We could not have a better reply to charges of technical inefficiency than the papers which are being read at this Conference. All branches of the science of the manufacture of iron and steel are dealt with, and there is one paper which describes a modern works recently built in this country. A study of this paper should convince our critics that we have thoroughly competent engineers and metallurgists, and that Heath Robinson is not the designing engineer to the industry, as perhaps some of their comments would imply.

Now I want to say a word of encouragement and advice to our young men. I strongly urge upon those who are engaged in every department, of the works, whether in the laboratory, research department or in the practical operations of the works, to follow what is going on in the industry in all parts of the world, and to read systematically and carefully the papers of scientific Institutes and technical journals. If they are young men with ideas, they should exercise their imaginations and endeavour to better everything with which they come in contact. Improvements are being made every day. With the growth of technical progress the man of sound ideas is probably required more to-day than ever, and if he will apply his mind to the problems in hand he may produce an invention which will be of service, and find that it is readily appreciated both here and in other countries. No country has a tariff against inventions. In my somewhat lengthy experience I have at times met some very ardent free-traders in this respect, who otherwise were staunch protectionists. The inventor may find difficulty in collecting a tariff or payment in just recognition of his work, but that should not discourage him, because some commercial men have peculiar ideas when dealing with inventors. Although invention is the basis of all progress, there are still some men in responsible positions who think that inventors are a

nuisance. My advice to young men is not to be discouraged, for success can only come from persistent effort, and although these islands are small, they should remember always that the world is large and is constantly looking out for improvements.

Like other organisations of a similar character, our Institute is feeling the absence of men who would have been members had they been alive to-day, but who made the great sacrifice in the war. We should like to see an increased membership, especially of young men. No doubt some think that membership of the local Institutes is sufficient. The local Institutes are doing valuable work, and are increasing in strength, but, in my opinion, by working in co-operation with this Institute they would strengthen their own position and that of our Institute. It should be remembered that this Institute holds a great international position. There are honours to be won which are prized all over the world. This is eminently illustrated by the presence here to-night of Mr. Charles M. Schwab, the President of the American Iron and Steel Institute. We would welcome more hearty co-operation of all Institutes both at home and abroad, and especially if they could influence their members occasionally to submit papers for acceptance here, so that they can obtain a national and international industrial publicity, which is one of the features of this Institute.

SECTION II.

*NOTES ON THE
PROGRESS OF THE HOME AND FOREIGN
IRON AND STEEL INDUSTRIES.*

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The Editor has been assisted in the preparation of these Notes by
R. ELSDON, Librarian of the Institute.

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Geology and Coal Resources of the Salina Canyon District, Sevier County, Utah. E. M. Spieker and A. A. Baker. (United States Geological Survey, 1928, Bulletin 796C).

Geology and Oil and Gas Possibilities of the Bell Springs District, Carbon County, Wyoming. C. E. Dobbin, H. W. Hoots, and C. H. Dane. (United States Geological Survey, 1928, Bulletin 796D).

Some Geological Features of the Washington Magnesite Deposits. S. S. Siegfus. (Engineering and Mining Journal, 1927, Vol. 124, Nov. 26, pp. 853-857).

Mineral Industry of Alaska in 1926. P. S. Smith. (United States Geological Survey, 1927, Bulletin 797A).

The Iron Ore Resources of Brazil and their Economic Importance. E. Teixeira. (Engineering and Mining Journal, 1927, Vol. 124, Nov. 5, pp. 730-735). The author discusses the occurrence and reserves of iron ores in Brazil. Minas Geraes is rich in iron, together with manganese, lime, and water-power, but lacks fuel and cheap transport. There are five blast-furnaces in that State and two in São Paulo, all of small size. Brief particulars of the plants are given.

ORES—MINING AND TREATMENT.

Geophysical Methods of Prospecting. A. S. Eve and D. A. Keys. (United States Bureau of Mines, 1927, Technical Paper No. 420). A brief and elementary account is given of the principles involved in the various methods of geophysical prospecting. The following four methods are dealt with : magnetic, gravitational, electrical, and seismic. Under each group the main topics of the physical principles involved are briefly discussed, and a diagram is given illustrating simple theoretical cases.

Geophysical Exploration for Ores. M. Mason. (American Institute of Mining and Metallurgical Engineers, 1927, Technical Paper No. 45).

Recent Results in Electrical Prospecting for Ore. H. Lundberg. (American Institute of Mining and Metallurgical Engineers, 1928, Technical Publication No. 98). The author discusses the general theory of electrical prospecting, and gives the essentials of practice and general observations on the cost. The results of various surveys are also discussed.

The Eötvös Torsion Balance Method of Mapping Geologic Structure. D. C. Barton. (American Institute of Mining and Metallurgical Engineers, 1928, Technical Publication No. 50). This paper deals with the theory of the Eötvös torsion balance, the factors determined by it, the interpretation of these results, and the limitations of the instrument in determining geological structure. A short bibliography is included in the paper.

A Cartographic Correction for the Eötvös Torsion Balance. C. A. Heiland. (American Institute of Mining and Metallurgical Engineers, 1928, Technical Publication No. 52).

Notes on Hematite Iron Ore Mining Methods and their Possible Application to Colliery Practice. A. Varty. (Paper read before the National Association of Colliery Managers, Mar. 3 : Iron and Coal Trades Review, 1928, Vol. 116, Mar. 23, pp. 415-417 ; Mar. 30, pp. 454-456). Illustrated notes are presented of the methods of mining iron ore in use on the north-west coast, together with particulars of the equipment used.

Development, Mining, and Handling of Ore in Folded and Faulted Areas, Red Iron Ore Mines, Birmingham District, Alabama. W. R. Crane. (United States Bureau of Mines, 1927, Technical Paper No. 407).

Method of Mining at Wabana. J. B. Gilliatt. (Transactions of the Canadian Institute of Mining and Metallurgy, 1927, Vol. 30, pp. 367-476).

The Demands made by Mining on the Materials of Drills and Hammers. G. Elster. (Glückauf, 1928, Vol. 64, Jan. 21, pp. 73-79; Jan. 28, pp. 111-118). The author discusses the peculiar conditions under which pneumatic drills and hammers are employed in mining. He gives numerous examples of failures, discusses their causes, and suggests remedies for the prevention of such breakdowns. Under the latter heading are included the choice of suitable materials for the construction of various parts, and their correct mechanical and heat treatment.

Improvements in Ferrous Sintering. E. J. Tournier. (Iron Age, 1928, Vol. 121, Jan. 19, pp. 191-193, 243). Improvements made in the design of sintering machines are briefly noted, and the equipment of the plant of the American Sintering Co., Hubbard, Ohio, for the sintering of flue-dust is described. The plant consists of conveying and mixing equipment, two 42 in. by 63 ft. 4 in. sintering machines, ignition system, blower, synchronising controls, electrical equipment, and dust-settling system. A flow-sheet indicating diagrammatically the materials in process is included.

Sintering a Variety of Materials. E. J. Tournier. (Iron Age, 1928, Vol. 121, Feb. 16, pp. 466, 510). The author discusses the possibility of the continuous sintering process for two particular types of raw materials—magnetic concentrates and iron-bearing ores.

Making Low-Grade Ores of Use. E. J. Tournier. (Iron Age, 1928, Vol. 121, Mar. 8, pp. 668-670). The concluding article of the above series dealing with the continuous sintering of ferrous materials.

Investigation of the Technical and Economic Possibilities of Carbonate Ore Concentration at the Iron Mine of San Fernando. W. Luyken and E. Bierbrauer. (Archiv für das Eisenhüttenwesen, 1928, Vol. 1, Jan., pp. 467-480; Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1928, Vol. 10, pp. 1-14). The San Fernando iron mine is near Herdorf in the Siegerland, Germany, and the ore is a carbonate, mixed with carbonates of manganese, lime, and magnesium. It consists mainly of excellent light brown, medium, and coarsely crystalline spathic ironstone, but penetrated in places with quartz veins. The

average composition is : Fe 32·69, Mn 6·70, Cu 0·33, SiO₂ 13·89 per cent. To obtain a good concentrate the copper pyrites and quartz must be separated. Hand-picking is most successfully employed, and the low-grade quartzite lumps are afterwards treated by a mechanical wet concentration process. The process is dealt with mainly from the economic point of view and less from the technical side. The product cleaned by the combined processes of hand-picking and wet concentration is 88·08 per cent. of the weight of the crude mineral, which when roasted is reduced to 61·08 per cent. of the weight of the crude mineral, the roast containing Fe 50·30, Mn 10·35, residues 10·72 per cent. The profit and loss account is very fully gone into. The cost of hand-picking comes out at 0·88 mark per ton, and of wet concentrating and recovery of the copper by electro-magnetic means at 4·41 marks per ton. The profit on each ton of ore treated appears to be 1·02 marks.

The Carbonate Ore Roasting Plant at the Mine of San Fernando, Herdorf. A. Weyel. (Stahl und Eisen, 1928, Vol. 48, Jan. 5, pp. 14-15). A section through the kiln is shown. The battery of 24 kilns, built in 1923, is of brick, the kilns being rectangular in plan and with thickly insulated walls. The dimensions of a kiln are 4·5 m. high, and $2 \times 2\cdot5$ m. area. Each treats 9 tons of raw carbonate per 24 hrs., the coke consumption being 4·5 to 5 per cent. of the weight of the raw ore, sorted by hand. The efficiency of the plant is very good.

The Apold-Fleissner Process of Roasting Carbonate Ore. R. Branhofer. (Stahl und Eisen, 1927, Vol. 47, Dec. 8, pp. 2061-2066). The Apold-Fleissner method of roasting carbonate iron ore consists in charging a shaft furnace with ore, which sinks continuously down while a current of hot air or flue gas, with a low content of carbon dioxide, is passed through the body of the ore and a current of cold air is passed upwards through the lower part of the shaft, this part acting as a cooling chamber for the ore and as a preheating flue for the air, which rapidly oxidises the ferrous oxide in the upper regions of the furnace. The quantity and temperature of the hot gases and cold air are carefully regulated, so as to keep the carbon dioxide content of the flue gas at a minimum, and thereby to ensure thorough roasting of the ore at the lowest possible temperature. A furnace roasting 200 to 450 tons per day requires about 160,000 to 200,000 kg.-cal. per ton, giving a heat efficiency of 73 per cent.

Magnetic Concentration of Iron Ores of Alabama. O. Lee, B. W. Gandrud, and F. D. de Vaney. (United States Bureau of Mines, 1927, Bulletin No. 278). This bulletin gives the results of magnetic concentration tests of the high-silica red ores, and the high silicate grey hematites of Alabama, and also includes the results of tests on the magnetic concentration of blast-furnace flue-dust.

Note on the Working of a Disc Crusher. P. Audibert. (*Revue de l'Industrie Minérale*, 1928, No. 171, Feb., pp. 81-88). Working tests made on the Simons disc crusher are described, and the advantages and disadvantages of this machine over roll crushers are discussed.

The Davies Electro-Magnetic Ore Separator. (*Engineering*, 1927, Vol. 124, Dec. 9, p. 746). This new design of magnetic separator for treating highly, moderately, or weakly magnetic material is described.

REFRACTORY MATERIALS.

Future Progress in the Field of Refractories. S. M. Phelps. (Paper read before the Iron and Steel Division of the American Society of Mechanical Engineers, Nov. 10, 1927 : Blast-Furnace and Steel Plant, 1927, Vol. 15, Dec., pp. 563-566). The author reviews briefly the lines along which progress may be expected to be made in the production and utilisation of refractories. He stresses the importance of co-operation between the manufacturer and user in solving the various problems to be faced.

Recent Investigation on Refractory Materials and their Application to Fuel Economy. A. B. Searle. (Fuel Economist, 1928, Vol. 3, Apr., pp. 461-463).

The Fireclay and Silica Industry in the Ukrain. (Feuerfest, 1928, Vol. 4, Mar., pp. 42-45).

The Selection and Use of Refractories for Iron Foundries. C. Presswood. (Paper read before the Institute of British Foundrymen: Foundry Trade Journal, 1928, Vol. 38, Jan. 19, pp. 43-47). The selection and use of refractory materials for foundries are considered, and desirable properties are discussed.

Refractory Natural Stone for Lining Cupolas and Converters. O. Beckmann. (Giesserei-Zeitung, 1928, Vol. 25, Mar. 1, pp. 156-159).

The Use of Silicon-Carbide Refractories in Boiler Furnaces. B. M. Johnson and J. A. King. (Journal of the American Ceramic Society, 1927, Vol. 10, pp. 100, 1007-1015). Some of the physical and chemical properties of different types of refractories are given. The development of bonded silicon carbide brick is mentioned. Clinker trouble is eliminated by use of these bricks in furnaces using all kinds of present-day stoker equipment. Failures due to chemical reaction between iron and silicon carbide, and torch action on a wall produced by a blast of flame under pressure, together with medium amounts of iron in the ash, are discussed. Air-cooling of walls is taken up. Installations of air-cooled silicon-carbide blocks are listed and discussed. Water cooling, the use of preheated air, and conditions of use of the water wall are dealt with.

The Influence of Oxidising and Reducing Atmospheres on Refractory Materials. A. E. J. Vickers. (Transactions of the Ceramic Society, Session 1926-27, Vol. 26, pp. 177-184). Experiments are described relating to the effects which different atmospheres produce when a refractory material containing pure ferric oxide is heated in them. N_2 , O_2 , and air have no detrimental effects, CO_2 is comparatively harmless, while CO , SO_2 , H_2 , and H_2O produce a very marked drop in the refractoriness of the materials investigated, the effect of H_2O being especially pronounced in this respect. The effects seem proportional to the amount of ferric oxide contained in the material.

The Important Properties and Requirements of some Special Refractories. M. F. Beecher. (Transactions of the American Society for Steel Treating, 1928, Vol. 13, Mar., pp. 473-484, 492). The properties of mullite, fused alumina, and silicon carbide are outlined. The common causes of failure in refractories are also pointed out.

The Deformation Test of Refractory Materials. H. Salmang. (Sprechsaal, 1927, Vol. 60, p. 477). The author describes an apparatus for testing the deformation of refractories. The apparatus consists of a furnace, a vertical plunger carrying weights by means of which the load is applied; a double planchette containing holes for an adjustable rod attached to a lever, which greatly magnifies and records the amount of deformation of the brick or material being tested. The pressure is applied vertically, and the load is kept constant throughout the test.

Investigations of the Slagging of Refractory Materials. H. Salmang. (Stahl und Eisen, 1927, Vol. 47, Oct. 27, pp. 1816-1820). In order to study the reactions of slag constituents with fireclay, fireclay crucibles were exposed to the direct action of those individual constituents. The slagging of the fireclay is dependent upon the proportion of bases in the slag and on the fluidity of the slaggy material. Pure oxides exercise the strongest attack; phosphates dissolve fireclay nearly as rapidly as oxides; and the action of complex silicates corresponds approximately to their content of bases.

A Review of the Literature on Laboratory Slag Tests for Refractories. R. F. Ferguson. (Journal of the American Ceramic Society, 1928, Vol. 11, Feb., pp. 90-98). A critical description is given of the numerous laboratory tests which have been proposed to determine the resistance of refractories to slag action.

The Prevention of Disintegration of Blast-Furnace Linings. H. K. Mitra and A. Silverman. (Journal of the American Ceramic Society, 1928, Vol. 11, May, pp. 278-291). Theories and observations on the causes of disintegration of fireclay refractories in blast-furnaces are given, and a process is developed for improving high iron clays for

this use. The disintegration of refractories in blast-furnace linings is initiated by spots of ferric oxide in the firebrick. Ferric oxide is reduced at 500°C . and hastens the cracking of 2CO to $\text{CO}_2 + \text{C}$, the carbon being retained by the lining. When Fe_2O_3 is converted to Fe_3O_4 the bricks will not disintegrate.

Investigations into the Destruction of Blast-Furnace Structural Materials, in particular of Fireclay Bricks. E. Diepschlag and K. Feist. (Feuerfest, 1928, Vol. 4, Apr., pp. 49-51). The authors first review the various conditions, mechanical, chemical, and physical, which the walls of the blast-furnace have to withstand. They then briefly discuss the results published by other investigators in this field, giving details of a test method devised by Hirsch, in which the refractory to be tested was formed into blocks in which holes were drilled or moulded; weighed quantities of alkali were inserted into these holes and the test-piece was then heated to the desired testing temperature.

The Lining of Electric Steel Furnaces. Kothny. (Feuerfest, 1928, Vol. 4, Feb., pp. 17-20; Mar., pp. 34-42). After a short review of the factors upon which the durability of linings depends and a recapitulation of the classification of electric steel furnaces, the number of furnaces throughout the world is tabulated. The advantages and disadvantages of acid and basic linings in radiation furnaces, and their present-day applications, are discussed. The process of lining a roof, and an acid and a basic hearth for a radiation furnace is described, attention being drawn to the precautions to be taken to ensure a maximum life. Finally, a detailed description of the lining of a low-frequency furnace and notes on that of a high-frequency furnace are given.

A Few Reflections on some New Processes for the Improvement of Refractories and for Protection against Soot. M. Seillan. (Chaleur et Industrie, 1928, Vol. 9, Mar., pp. 152-153). Neutron and Capol, both colloidal solutions of graphite, are proprietary articles intended for protecting the surfaces of furnaces. The former is applied by painting, cement gun, or other means to the refractories to prevent their destruction by slags or other agents; the latter is intended to make the removal of soot from boiler tubes more easy.

Biasbrix. (Blast-Furnace and Steel Plant, 1928, Vol. 16, Feb., p. 275; Heat Treating and Forging, 1928, Vol. 14, Feb., p. 212). The difficulty of preventing furnace walls from loosening up and joints from opening is said to be overcome by the use of refractory bricks cut on the slant. Each brick in any given course of the masonry overlaps three bricks in the adjacent courses, so providing an exceptionally strong bond.

Carbon Crucibles for High Temperatures. M. K. Hoffmann. (Zeitschrift für Elektrochemie, 1927, Vol. 33, May, pp. 200-202). It was

found that by heating crucibles in electric furnaces with a colloidal solution of a carbide-forming oxide, the heat resistance can be greatly increased. Treated crucibles will withstand temperatures of more than 2000° C. for a considerable time. Silica treatment is recommended for all metals which will not react with SiC.

The Temperature Diffusivity and Thermal Conductivity of Silica Refractory Material at High Temperatures. A. T. Green. (Transactions of the Ceramic Society, Session 1926-27, Vol. 26, pp. 159-167). The modern well-fired silica product has a relatively high coefficient of thermal conductivity and temperature diffusivity at the higher temperatures. In fact, the extra heat-treatment which this product receives appears to have a decided determining influence on its heat conductive properties. Inefficient heat treatment results in the production of a very poor conducting product, which has a remarkably low value for the coefficient of temperature diffusivity. The rate of increase of temperature diffusivity of a very porous product with temperature at higher temperatures is very pronounced. This points to the influence of pore-spaces in helping the transmission of heat at high temperatures (1100° or so).

A Comparison of the Temperature Diffusivities and Thermal Conductivities of Silica and Fireclay Refractories. A. T. Green. (Transactions of the Ceramic Society, Session 1926-27, Vol. 26, pp. 168-175). The diffusivities of silica and fireclay products are compared. In general, the diffusivities of silica products, both at lower (700°) and higher (1200°) temperatures, are higher than those of fireclay products. However, it is emphasised that there are decided variations in the values for individual samples of both kinds of refractory materials, and thus there are examples of fireclay products which have higher values for this constant than some silica products. The influence of the value of the apparent specific gravity on the value of the coefficient of thermal conductivity of both silica and fireclay materials is discussed in detail. It is shown that the apparent specific gravity of a well-fired silica brick is considerably less than that of a fireclay brick, and consequently this tends to give lower values for the coefficient of thermal conductivity of silica products. Some of the superior well-fired silica bricks are better conductors of heat than the average fireclay product at lower temperatures (800°). Many silica bricks and firebricks have approximately equal conductivities at lower temperatures (800°). Most silica bricks—except those which have received ineffective firing—are better conductors than firebricks at higher temperatures (1200°). Poorly burned silica bricks are comparatively poor conductors. Silica bricks, in general, show a greater rate of increase of diffusivity and thermal conductivity with temperature than firebricks. It is indicated that a material possessing a low porosity is not necessarily a good conductor of heat. In many cases the reverse is the case, particularly at high temperatures. The rate of increase of temperature, diffusivity, and

thermal conductivity is seen to be very high in the case of certain materials possessing high porosity. Materials with close sandy textures, possessing comparatively high porosities, have, in the majority of investigated cases, shown either relatively high diffusivities and thermal conductivities or very pronounced rates of increase of diffusivity and thermal conductivity with temperature at high temperatures.

Silica and Fireclay Refractories. A. T. Green. (Paper read before the Institute of Chemical Engineers, Dec. 9. 1927 : Gas Journal, 1928, Vol. 181, Jan. 4, pp. 40-42). With regard to texture of fireclay products, the refractoriness of a coarse-grained product is greater than that of a fine-grained one, other factors being equal. In general, it is found that a fine texture is more effective in the carbonising industries, whereas the coarser material finds great favour in the steel industry. The author discusses refractoriness under load, after-contraction and after-expansion, spalling, temperature diffusivity, and thermal conductivity of fireclay and silica products and insulation.

A Consideration of the Properties of Silica and Fireclay Products in Relation to the Carbonising Industries. A. T. Green. (Paper read before the Carbonising Conference, Feb., 1928 : Gas Journal, 1928, Feb. 14, Special Number, pp. 65-77). The subject is discussed under the following headings : texture and constitution of fireclay, siliceous and silica products ; the disintegration, corrosion, and erosion of silica and fireclay products, with particular reference to carbonising conditions ; the technical conception of the structural stability of silica and fireclay products ; thermal properties.

The Properties of Silica and Fireclay Products in Relation to their Industrial Usage. A. T. Green. (Iron and Coal Trades Review, 1927, Vol. 115, Dec. 16, p. 897). The behaviour of refractory bricks in coke-ovens and open-hearth furnaces is briefly described.

The Control of Silica Brick-Making, Based on Load-Test Indications. A. J. Dale. (Transactions of the Ceramic Society, Session 1926-27, Vol. 26, pp. 203-230). In Part I. it is suggested that the internal changes occurring during the manufacture of silica bricks are capable of a simple theoretical explanation, and a theory which, in the main, is in close accord with facts is advanced. The indications of previous load-test work, in so far as they concern the silica-brick maker, have been recapitulated. In Part II. possible methods of controlling the preparation of the larger grades of rock incorporated in a raw brick mix are outlined. The adjustment of the constitution and properties of a silica brick to its future industrial application is considered in Part III., and three very general and comprehensive types of industrial usage are defined. In Part III., also, the effect of matrix nature on the mechanical properties of silica bricks at high temperatures is reviewed,

and the applications of these considerations to the control of the matrix fractions are followed to their logical conclusions in Part IV.

The Spalling of Silica Refractory Material at Low Temperatures. A. T. Green and H. Edwards. (Transactions of the Ceramic Society, Session 1926-27, Vol. 26, pp. 185-202). The factors influencing the spalling of silica products at low temperatures—*i.e.* diffusivity, volume changes, and elasticity—are considered. Expansion data for eight products have been obtained. These data indicate differences in the constitutions of these materials, particularly with respect to the relative amounts of tridymite and cristobalite present. The amount and the influence of the firing which the products have received are discussed on the basis of the data of expansion, the true specific gravity, and the lime contents. The α to β_1 , β_1 to β_2 tridymitic transformations, together with α to β cristobalitic transformations, are given some quantitative significance from the point of view of expansion data. The cristobalitic change is shown to be particularly effective in causing spalling, while the tridymite change also causes it, if to a less extent. Data for the coefficient of temperature diffusivity of the materials are given. There is apparently no connection between the diffusivity and the spalling tendency under the conditions of these experiments. The elasticity of the product plays an important part in the spalling of silica products at low temperatures. The influence of the amount and nature of the matrix is discussed in this connection.

The Heat Expansion of Refractory Bricks. K. Schönert. (Archiv für das Eisenhüttenwesen, 1927, Vol. 1, Nov., pp. 379-386). The author reviews and summarises the work of previous investigators of the expansion properties of refractories in common use on heating. Silica bricks, fireclay, magnesite, chromite, and carborundum bricks are dealt with. In the case of the three first-named types much information is already available and is presented by the author. Chromite bricks and carborundum bricks have not been subjected as yet to complete investigation. Such information as is available shows that the coefficient of expansion of chromite rises rapidly up to 200°, then remains fairly constant to 1300°, after which it falls. In carborundum the expansion rises quite regularly from 0 to 0.4 per cent. at 1000° C.

The Expansion of Firebricks when Heated. A. B. Searle. (Fuel Economist, 1927, Vol. 3, Nov., pp. 115-116). Expansion curves of silica bricks and other refractory materials are shown.

The Importance of the Elasticity and Thermal Expansion of Refractory Clays and their Influence on the Spalling of the Fired Product. R. F. Geller. (American Refractories Institute, Oct. 1927, Technical Paper No. 4; Feuerfest, 1928, Vol. 4, Jan., pp. 6-9). The

results of tests on a number of American clays are reported. It is shown that the thermal expansion and porosity of the fired material are very important factors which are closely related to the resistance to spalling. The difference between the thermal expansion of the clays, or the clay and grog, in a mixture determines the degree of deformation which the mixture will withstand. The properties of the clays composing a refractory are sufficiently diverse to cause destructive internal stresses or structural changes in the material after prolonged heating; as a result of the latter, the heated portion of the refractory behaves differently to the cold part. The individual properties of the clays are masked when mixed together in the refractory, and they should be determined separately.

The Importance of Thermal Dilatation in the Valuation of Refractory Products. W. Miehr, J. Kratzert, and H. Immke. (*Tonindustrie-Zeitung*, 1927, Vol. 51, Mar. 30, pp. 417-422). The authors describe an apparatus for determining the thermal dilatation of refractories. The test-piece in the form of a rod is heated in a vertical electric tube furnace, and the movement of its free end is transmitted through a lever to a long needle which travels over a scale. The temperature of the test-piece is measured by a thermocouple.

The Properties of Magnesite Bricks. H. Hirsch. (*Archiv für das Eisenhüttenwesen*, 1927, Vol. 1, Dec., pp. 439-444). Tests were made on magnesite bricks with magnesia ranging from 83.7 to 97.6 per cent. The complete composition of 15 specimens of bricks is given. The results are tabulated, showing porosity, specific gravity, volume, softening point, expansion, wear, compressive strength cold, and at 1200°. X-ray photographs of molten magnesia and micrographs of good, medium, and indifferent magnesite bricks are shown.

Plasticity of Clays. L. E. Jones. (*Journal of the American Ceramic Society*, 1928, Vol. 11, May, pp. 317-322). The cause of the plasticity of clay is the formation in the moistened clay of a continuous external phase through the action of water in making gelatinous the material that forms the enveloping surface around the non-gelatinous particles and aggregates present in the clay. Peptising and flocculating effects of electrolytes and organic matter are discussed. A possible method for evaluating the relative plasticity of clays and the results obtained on some commercial clays, using this method, are given.

Progress Report on Investigation of Sagger Clays. Their Elasticity, Transverse Strength, and Plastic Flow at 1000°C. R. A. Heindl. (*Journal of the American Ceramic Society*, 1927, Vol. 10, pp. 995-1004).

Some Observations on the Dehydration and Firing Behaviour of Clays. R. F. Geller and W. H. Wadleigh. (*Journal of the American Ceramic Society*, 1927, Vol. 10, pp. 925-955).

Practical Experience of Firing Refractory Materials with Oil. F. West. (Paper read before the Ceramic Society: Iron and Coal Trades Review, 1928, Vol. 116, Mar. 16, p. 385). The results are presented of experiments with the use of oil fuel for the firing of silica refractories at the Friden Works, near Buxton. Comparative results with coal and oil burning, together with particulars of cost, are tabulated.

Fire-Travel in Continuous Kilns. A. B. Searle. (Journal of the American Ceramic Society, 1928, Vol. 11, Mar., pp. 143-156). A general comparison is made of tunnel kilns and other continuous kilns for firing refractory brick, with special reference to size, condition of the brick entering the kiln, draught, and rate of firing.

Kilns and Fuels for Firing Refractories. W. E. Rice. (American Refractories Institute, Sept. 1927, Bulletin No. 15).

A Machine for Dressing Firebricks. (Iron and Coal Trades Review, 1928, Vol. 116, Mar. 23, p. 424). Brief particulars are given of a machine in which firebricks can be dressed to the required size, squared off, bevelled, and their surfaces smoothed with great precision.

The Thermal Insulation of Furnaces and Kilns. A. E. Hubbard. (Fuel Economist, 1927, Vol. 3, Dec., pp. 169-173). By the use of suitable insulating materials radiation losses can, in most cases, be reduced by 75 per cent.; the chief exception being melting furnaces where, at the present time, the use of insulation has to be limited to regenerators or recuperators, uptakes and gas mains, owing to the fact that the operating temperatures are too near to the limit of refractoriness of the lining bricks to permit of insulating crowns and side walls. The material from which most of the insulators for furnaces are made is diatomaceous or infusorial earth. It is particularly suitable as a covering for the crowns of annealing and reheating furnaces.

In deciding whether or not insulation can be applied to a high-temperature furnace, the softening range of the firebricks used as a lining is, in most cases, the governing factor.

The Prevention of Air Leaks through the Masonry of Boilers and Furnaces. The Plastic Heat Insulator "Seal-a-Set." J. Thomas. (Génie Civil, 1928, Vol. 92, Feb. 18, pp. 166-167). The author discusses the ill-effects on the efficiency produced by the leakage of air into furnaces. "Seal-a-Set," which is much used in America for the prevention of these leaks, consists of a mixture of asbestos fibres and of special bitumens; it is a very adhesive paste, which is applied on the outside walls of the masonry in layers from 2 to 3 mm. thick. After two or three days it forms a sort of skin, which is perfectly air-tight and elastic.

FUEL.

PROPERTIES, PREPARATION, MANUFACTURE, AND USES.

FUEL TECHNOLOGY.

The Calculation of the Calorific Value of Fuels from their Chemical Composition. R. Von Dracek. (*Brennstoff-Chemie*, 1927, Vol. 8, Jan. 15, pp. 22-23). The author criticises the formulæ for the evaluation of the calorific value of fuels proposed by several other authors; his own experiments lead to the conclusion that their equations are not applicable to fuels of widely differing types obtained from different sources. He puts forward a formula of his own devising, which over a period of five years has given results agreeing with the calorimetric tests to within 0·5 per cent. and hardly ever deviating by more than 1 per cent.

Concerning Calorific Power. P. Jarrier. (*Chaleur et Industrie*, 1928, Vol. 9, Mar., pp. 122-126). A general discussion of the subject.

On the Theory of Heat. H. Le Chatelier. (*Transactions of the American Society for Steel Treating*, 1928, Vol. 13, Apr., pp. 555-572). In this discussion of the theory of heat, the author covers the problems of suitable heating—the supplying simultaneously of the required amount of heat and the temperature necessary for carrying out the contemplated action; also the cost of heating—fuel, labour, and maintenance—which is exactly proportional to the consumption of calorific energy. The author points out that there are many factors which play an important part in heat theory—for instance, the transfer of heat and its utilisation are controllable by the laws of energetics, also the effect of passive resistance and conditions of reversibility. The different types of perfected apparatus are explained, particularly the shaft furnace, with its current of gases, and the burning of quartz is followed through. The importance of an even distribution of temperature within the furnace and its necessary limitation as applied to the melting cupola are also dealt with.

The Progress of Fuel Technology in Germany in 1927. A. Grounds. (*Fuel Economist*, 1928, Vol. 3, Jan., pp. 210-216). Some of the more

important developments which have taken place in Germany in the use of fuel are reviewed.

The Use of Fuels, Past and Present. S. W. Parr. (Paper read before the First National Fuels Meeting, Oct. 10, 1927: Forging, Stamping, Heat Treating, 1927, Vol. 13, Oct., pp. 401-402, 404). The history of the use of coal and other fuels in America is given, together with consumption figures.

Clinkering Characteristics of Coal. A. C. Fieldner, W. A. Selvig, and P. Nicholls. (Paper read before the American Society of Mechanical Engineers: Fuels and Furnaces, 1927, Vol. 5, Dec., pp. 1609-1610). The authors describe the results of an investigation of various coals as to their composition and behaviour when burned. The quantity of clinker formed decreases as the rate of burning increases, although the density and fusion of the clinker pieces are greater at the higher rates. The rate of decrease of quantity with rate of burning becomes less when the coal ash fusion temperatures are low. The quantity of clinker formation has a fairly definite relation to the softening temperature of the coal ash as determined by the standard gas furnace method. It decreases with increase of temperature, and has small change for coals having a softening temperature greater than 2600° F. This relation is better expressed by using the softening temperature than it is by that of the initial or fluid temperatures.

Economies of Electric and Fuel Furnaces. C. L. Ipsen and A. N. Otis. (Forging, Stamping, Heat Treating, 1927, Vol. 13, Nov., pp. 439-442). A comparison of electric and fuel-fired furnaces is made from the economic viewpoint.

Characteristics of Industrial Furnaces. V. J. Azbe. (Paper read before the American Society of Mechanical Engineers, Apr. 5, 1927: Heat Treating and Forging, 1928, Vol. 13, Dec., pp. 484-487). The importance of relative temperatures of heat-radiating and heat-absorbing media, the effect of efficiency of low CO₂ and excess air, and the cost of steam for blowing are discussed.

Practical Industrial Furnace Design. W. H. Mawhinney. (Forging, Stamping, Heat Treating, 1927, Vol. 13, Oct., pp. 417-419, 428; Nov., pp. 452-455; Heat Treating and Forging, 1927, Vol. 13, Dec., pp. 497-500, 504; 1928, Vol. 14, Jan., pp. 81-84; Feb., pp. 189-193, 197). The continuation of a series of articles (*see* Journ. I. and S.I., 1927, No. II. p. 491). The kinds of brick used in the construction of furnaces and the manner of laying them are described. The question of insulation is considered. The various metal parts required in a furnace and their design are studied. The temperature and atmosphere within the furnace, temperature measurements, and

various types of pyrometers and their operation are described. Automatic control and its advantages are dealt with.

Investigation of Temperature and Gas Composition in the Combustion Chambers of Shaft Furnaces. E. Diepschlag. (*Die Giesserei*, 1928, Vol. 15, Jan. 6, pp. 3-6).

Calculation of the Combustion Temperature in Shaft Furnaces. K. Mühlbradt. (*Stahl und Eisen*, 1927, Vol. 47, Oct. 27, pp. 1813-1816). The article deals mainly with the theory of combustion in gas-producers and cupola furnaces.

Operating Experiences with 1300 lb. Steam Pressure. J. Anderson (*Journal of the Institute of Fuel*, 1928, Vol. 1, Jan., pp. 131-160). A record is given of the actual operating experiences with a water-tube steam boiler of 240,000 lb. evaporation per hr., installed at the Lakeside Power Station, Milwaukee, U.S.A., and generating steam at a pressure of 1300 lb. per sq. in. Various troubles experienced with the boiler are described in detail, and also the remedies. These troubles are confined almost wholly to tube failures from scale formation and tube corrosion.

Measurement of Steam Flow in Works' Practice. H. C. Armstrong and T. Nordenson. (*Journal of the Institute of Fuel*, 1928, Vol. 1, Jan., pp. 161-186). Attention is called to the very valuable economies that result from the use of steam meters for the investigation, in detail, of the actual steam consumption of different steam-consuming processes in works. The type of apparatus that, according to the authors' experience, fulfils the best conditions to the greatest degree is the simple throttle-orifice diaphragm meter with "slip-in orifice."

Economy in Steam Raising. R. Wigginton. (*Transactions of the Institution of Mining Engineers*, 1926, Vol. 70, p. 274). The author's intention is to show how fuel economy may be practised in small boiler plants with steam pressures of about 130 lb. per sq. in., where elaborate and expensive plant is impossible. Probably about half the steam generated in this country comes from small units of this type.

The Ruths Steam Accumulator. E. Ingham. (*Colliery Guardian*, 1928, Vol. 136, Feb. 17, pp. 627-629).

Preheated Air for Boiler Furnaces. P. H. N. Ulander. (*Journal of the Institute of Fuel*, 1928, Vol. 1, Jan., pp. 187-201). In most cases boilers equipped with preheaters show a flatter efficiency characteristic than similar boilers working on cold air. This may partly be explained by the fact that a higher furnace rating can be

maintained without serious loss due to incomplete combustion. It has invariably been found that when preheated air is used and the grates have been of suitable design, the combustible in the refuse has been less than with cold air under otherwise similar conditions. The most effective way of keeping down the furnace temperature, and thus eliminating one of the serious objections to preheated air, is, however, to arrange the heating surface in such a way that a large amount of heat can be absorbed by direct radiation, and to provide for sufficient combustion chamber space to keep the furnace rating within reasonable limits.

Heat Transmission through Boiler Tubes. (Engineer, 1928, Vol. 145, Feb. 10, pp. 165-166). A résumé is given of a paper by H. O. Croft, published by the University of Illinois, dealing with the rate of transmission of heat through boiler tubes from the outside inwards. As a result of the investigation the following conclusions may be drawn: (1) The coefficient of heat transmission of the apparatus is affected by (a) the rate of gas flow; (b) the temperature difference between the flue gas and water; (c) the pressure at which steam is generated; (d) the temperature of the gas stream. (2) The water velocity in the tube has slight effect on the overall coefficient of heat transmission. (3) The water velocity in the inclined tube of the apparatus varies as the steam rate and total energy input, and tends to approach a practical maximum at slightly over 3 ft. per sec. (4) The water velocity is affected by the steam pressure. (5) The temperature gradient from the flue gas to the water in the tube varies with the flue gas temperature, the rate of gas flow, and the steam pressure.

Heat Exchanges in the Hearth of a Furnace. E. Damour. (Chaleur et Industrie, 1928, Vol. 9, Mar., pp. 111-121). The theory of the flame, temperature of combustion, thermal potential, &c., are studied.

Principles and Applications of Recording Instruments for Remote Control. K. Gross. (Stahl und Eisen, 1928, Vol. 48, Mar. 8, pp. 297-306). A number of different types of instruments, operated either by mechanical or by electrical means, for measuring and recording the working of engines, dynamos, gasometers, the operation of blast-furnaces, and coke-ovens, are described, and the principles on which such instruments work are explained. A diagram is given showing a proposed arrangement of a central station in which all the recording instruments for controlling operations in a large ironworks are assembled.

Practical Pyrometry. J. R. Collins. (Fuels and Furnaces, 1928, Vol. 6, Mar., pp. 301-308). An account is given of the various temperature scales, and of the characteristics of typical pyrometers.

The Registration of Industrial High Temperatures. V. Charles. (*Arts et Métiers*, 1928, Vol. 81, Feb., pp. 62-75). Pyrometers used in the measurement of high temperatures are described and discussed.

The Automatic Regulation of Furnaces. A. Chagnaud. (*Revue de Métallurgie, Mémoires*, 1928, Vol. 25, Feb., pp. 87-89). The "Eutactic" automatic temperature controller for use with electric or gas-fired furnaces is described.

The Rôle of Temperature-Regulating Instruments. F. Jombart. (*Revue de Métallurgie, Mémoires*, 1927, Vol. 24, Oct., pp. 573-590). Various types of temperature-controlling devices, and the manner in which they operate, are described. Heating and cooling curves of furnaces controlled in various ways are reproduced.

Combustion Control for Industrial Furnaces. F. J. Ryan. (*Iron and Steel Engineer*, 1927, Vol. 4, Dec., pp. 493-498). Automatic combustion and temperature control of heating furnaces is dealt with.

Proper Combustion for Furnaces. W. P. Chandler, jun. (*Iron and Steel Engineer*, 1928, Vol. 5, Jan., pp. 16-17). The correct proportioning of air in furnaces is briefly discussed, and particulars are given of a Huessener automatic combustion control apparatus. Results obtained with the use of this apparatus are given.

Gas Engines or Steam Turbines. F. Bartscherer. (*Fuel Economist*, 1927, Vol. 3, Nov., pp. 119-124; Dec., pp. 175-181). The author discusses the conditions which determine the economy of a heat engine. (*See also Archiv für das Eisenhüttenwesen*, 1927, Vol. 1, Oct., pp. 297-312; *abstr.*, *Journ. I. and S.I.*, 1927, No. II. p. 509).

Pig Iron and Power. (*Engineer*, 1927, Vol. 144, Nov. 18, pp. 560-561, 570). The Staveley Coal and Iron Co. generates about 54 million units of electricity in a year, while each of the four blast-furnaces which give off the gas necessary for the generation of that amount of power produces from 900 to 1000 tons of pig iron per week. 15 to 20 per cent. of the power generated in the works is sold outside, to collieries, towns, and other users. The article describes the manner in which the gas is treated, and the gas engines and electrical plant used in generating and regulating the current.

Power Plants of Pittsburgh Steel Company. W. E. Reed. (*Blast-Furnace and Steel Plant*, 1928, Vol. 16, Jan., pp. 74-76). A comprehensive outline of the power equipment of the various works, with details of power units.

A Modern Steelworks Blowing Plant. W. Sykes. (Paper read before the American Iron and Steel Institute, May 25, 1928). A detailed illustrated account is given of the new power and blowing plant of the Inland Steel Co., Chicago, together with some operating results, and costs.

Presidential Address. H. E. Wright. (Proceedings of the Cleveland Institution of Engineers, Session 1927-28, No. 1, pp. 12-34). The author discusses the efficient utilisation of fuel in iron and steel works, and points out where savings can be effected.

Fuel Control. H. C. Armstrong. (Fuel Economist, 1928, Vol. 3, Mar., pp. 329-332; Apr., pp. 451-455). The author surveys the chief factors in the lowering of fuel costs in steelworks.

The Influence of Fuel on Industrial Costs. (A Symposium held by the Institute of Fuel, Mar. 14, 1928). The subject was discussed from the points of view of the road transport, colliery, iron and steel, cement, and electric power supply industries. The problem was discussed from the coal-mining point of view by K. M. Moss, and from that of the iron and steel industry by E. C. Evans.

The Development of Heat Economy in the Iron and Steel Industry. H. Lent. (Stahl und Eisen, 1927, Vol. 47, July 21, pp. 1189-1196. *Abridged Translation*, Iron and Coal Trades Review, 1927, Vol. 115, Nov. 11, pp. 713-714).

Waste-Heat Recovery. W. Gregson. (Paper read before the Institution of Mechanical Engineers, Feb. 18, 1928: Engineering, 1928, Vol. 125, Feb. 24, pp. 241-243, Mar. 2, pp. 272-273; Iron and Coal Trades Review, 1928, Vol. 116, Feb. 24, pp. 251-254). In a complete steel plant comprising coke-ovens, blast-furnaces, melting shop, and mills, by proper organisation and by the utilisation of all of the surplus industrial gas, including waste-heat recovery, the works can depend entirely for the whole of its metallurgical gas and power on the coal supplied to the ovens, *i.e.* approximately 32 cwt. per ton of pig iron. The arrangement of a self-contained steelworks laid out on these lines is shown diagrammatically. Waste heat as distinct from surplus gas is available from the following sources in the steelworks: (1) Waste heat from coke-ovens where they are of the non-regenerative type; (2) sensible heat in the incandescent coke and blast-furnace slag; (3) exhaust from the blast-furnace gas engines driving the blowers; (4) flue gases from the mixer, the melting furnace, the soaking pits, and the mill reheating furnaces.

A fuel consumption figure representing general practice in melting furnaces, soaking pits, and reheating furnaces is $9\frac{1}{2}$ cwt. per ton of finished steel. Taking an average steam production figure of $2\frac{3}{4}$ lb.

per lb. of producer fuel, the steam yield per ton of finished steel works out at 2920 lb. Assessing this steam at $7\frac{1}{2}$ lb. per lb. of fuel of calorific value of 12,000 B.th.u., the equivalent fuel saving is 390 lb. or approximately $3\frac{1}{2}$ cwt. Hence the net fuel consumption per ton of steel is 6 cwt., and the fuel saving 37 per cent. To obtain a correct overall figure for the works, 550 lb. of steam per ton of pig from the blowing engine should be added. Assuming three-fifths pig and two-fifths scrap, the proportion per ton of steel becomes 330 lb. This increases the total steam saving to 3250 lb. and the equivalent fuel saving to 435 lb. or 3.9 cwt., whence the net fuel consumption per ton of steel becomes 5.6 cwt. and the proportional saving 41 per cent. It should be noted that these figures are purely waste-heat recovery figures, no credit having been taken for the surplus coke-oven gas and blast-furnace gas, which, with regenerative coke-ovens, works out in average English practice at a total heat in gas per ton of pig of 12,920,000 B.th.u.

Waste-Heat Boilers. R. H. Stevens. (Paper read before the American Iron and Steel Institute, May 25, 1928). Consideration is given to gas temperatures involved, composition and heating value of the gases, proper location of the boiler in relation to the open-hearth furnace and the electric power generating plant, steam pressures obtainable, possibility of explosion on valve reversal, fans for draft, superheaters and economisers, air infiltration, draft requirements and heat losses. The author concludes that while the generation of steam is, in general, a feasible way of recovering waste heat, an installation for the purpose is apt to be most expensive and the ultimate results no better than those possible with a less costly scheme. Metallic recuperators are now capable of receiving the hot burned gases as high as 1600° F., or higher. This seriously affects the justification for waste-heat boilers, and when used in connection with regenerators may exclude the necessity for installing a steam generating unit. Complete utilisation of heat by the primary heating unit promotes economies in excess of those represented by the performance of the waste-heat boiler.

Reduction of Steelworks Costs by Means of Waste-Heat Boilers. J. Adamson and F. Jones. (Paper read before the Institution of Mechanical Engineers: Iron and Coal Trades Review, 1928, Vol. 116, Jan. 6, pp. 1-3). The advantages claimed for water-tube and fire-tube waste-heat boilers are discussed, and the economies possible with the use of waste-heat boilers in combination with blast-furnaces, open-hearth furnaces, soaking pits, and reheating furnaces are shown. The financial savings effected with waste-heat boilers are also tabulated.

Utilising Waste Heat by Means of Boilers. (Blast-Furnace and Steel Plant, 1928, Vol. 16, Apr., pp. 508-510). A brief discussion of

the economies to be derived from the utilisation of the heat from the spent gases from gas engines, producers, and steel furnaces.

Surplus and Waste Heat in Fuel Economy. J. W. Reber. (Fuel Economist, 1928, Vol. 3, Jan., pp. 237-240).

COAL.

The Petrography of Coals. Mining and Industrial Applications. R. Van Aubel. (Revue de l'Industrie Minérale, 1928, Feb., No. 171, pp. 69-80). The author describes special petrographic methods used in the microscopic examination of coals. He describes the preparation of the specimens by the production of thin sections, polished sections, and by the adaptation of metallographic methods. He deals with micro-chemical methods of identifying certain substances in these sections, and also, very briefly, with the X-ray examination of coals. Finally, he shows the application of the petrography of coals to various mineral and industrial questions.

The Control of Fuels by X-Rays. (Radio Carboscropy). P. Parandel. (Chaleur et Industrie, 1928, Vol. 9, Feb., pp. 98-100). The use of X-rays for the examination of coals is outlined.

Microstructure of New Zealand Lignites. W. P. Evans. (New Zealand Journal of Science and Technology, 1927, Vol. 9, Sept., pp. 137-158; Fuel, 1928, Vol. 7, Feb., pp. 75-83). In this section (Part II.) lignites subjected to the action of igneous intrusions are dealt with (*see* Journ. I. and S.I., 1927, No. II. p. 494). It is concluded that the brighter parts of the Steventon lignite are chiefly formed from coniferous woods, the attritus being also largely made up of such woods. Spores, mostly megaspores, of small dimensions, occur definitely though infrequently. Silica, as cryptocrystalline chalcedony and as unbanded colloidal masses, accounts for much of the ash. Sulphur has been transferred from organic to inorganic compounds by the action of dolerite intrusions. The coal-forming deposit consisted chiefly of transported material, and was laid down under water.

Banded Coal. H. Winter. (Glückauf, 1927, Vol. 63, Apr. 2, pp. 483-491; Fuel, 1928, Vol. 7, Feb., pp. 52-63). The results of a chemical and microscopical investigation of banded bituminous coal from the Ruhr district are published, with criticisms of Dr. Stopes' classification of the ingredients of banded coal.

The Carbonisation and Combustion of Particles of Coal: The Structure of Cenospheres. F. S. Sinnatt. (Transactions of the Institution of Mining Engineers, 1926-27, Vol. 73, pp. 147-168).

The Action of Concentrated Sulphuric Acid on Different Kinds of Coal. D. J. W. Kreulen. (Brennstoff-Chemie, 1927, Vol. 8, May 15, pp. 149-154). The samples studied contained 41.3, 28.4, 22.8, and 15.4 per cent. of volatiles respectively. 5 grm. of coal were treated with concentrated acid until a homogeneous mass was obtained; a reaction, characterised by the evolution of SO_2 , took place, and was stopped after 3, 6, or 10 minutes by the addition of water. The modifications in the quantities of tars, phenols, coke, &c., introduced by the treatment were studied. The acid was found to act as an oxidiser; the phenols were diminished in quantity, but the resins and waxes derived from hydrocarbons were not affected.

The Reactions between Oxygen and Coal. W. Francis and R. V. Wheeler. (Journal of the Chemical Society, 1927, Dec., pp. 2958-2967). The behaviour of the hydrogen-containing ulmin molecule during the oxidation of the coal was studied. Experiments were made on the vitrain portion of newly won coal and on vitrain from the same seam after transformation into soluble ulmins by prolonged atmospheric oxidation at 150°C .

The Adsorption of Oxygen by Preheated Coal. G. Coles and J. Ivon Graham. (Fuel, 1928, Vol. 7, Jan., pp. 21-27; Researches of the Spontaneous Combustion Committee of the Safety in Mines Research Board). The results of a careful investigation on coals from various districts show that, if certain coals have been preheated, their liability to spontaneous firing is greatly increased.

Action of Bacteria on Coal. W. Fuchs. (Brennstoff-Chemie, 1927; Fuel, 1928, Vol. 7, Jan., pp. 28-30). Previous work by Renault, Potter, Galle, and Wheeler on the action of bacteria is reviewed and summarised. New investigations by the author are directed towards finding whether bacteria can liberate inflammable gases from coal. If initial oxidation of coal is due to the action of bacteria, there may be a simple means of preventing the oxidation and spontaneous heating of coal by spraying it with some solution which would destroy the bacteria. The subject is one for further research.

Clean Coal in the Coking Industry. R. Lessing. (Paper read before the Coke-Oven Managers' Association, Mar. 31, 1928: Colliery Guardian, 1928, Vol. 136, Apr. 5, pp. 1336-1338). The importance of clean coal in the manufacture of metallurgical coke is pointed out. It is considered good practice to prepare coal yielding an 8 per cent. ash coke, and a 10 per cent. ash coke may be taken to represent the average

produced in this country. This figure would be equivalent to from 6.7 to 7 per cent. of ash in the coal carbonised. To this total only from 1 to 1.5 per cent. is contributed by the inherent ash of the coking fraction, while the balance is derived from the dirt of non-coking coal slack. A table is given showing the rational composition of the ash in coke obtainable from two types of slacks cleaned to different degrees of purity.

Notes on Coal Cleaning and its Relation to the Cost and Quality of Coke. G. W. J. Bradley. (Fuel, 1928, Vol. 7, Jan., pp. 31-37). Records are given of an investigation into the working of a Coppée washer, in the operation of which troubles had arisen, due to too large a proportion of fines in the coal, which led to difficulties with drainage and slurry. By screening out the dust smaller than $\frac{1}{16}$ in. before washing, the trouble was overcome, but on remixing the dust with the washed coal prior to grinding, great variation in the ash was found. The cause was traced to the fact that the ash content of different sizes of the same coal may vary from about 12 per cent. in coal of $\frac{3}{8}$ to $\frac{1}{4}$ in. up to 20 per cent. in the dust passing a 60-mesh screen, while in the sinkings it is very much higher. The fine slurry-making materials should be withdrawn from the coking slack prior to washing, and should not be remixed with the washed coking slack. The fines are useless from the coking standpoint, particularly in the case of South Yorkshire coals. It is suggested that payment to a colliery should be based on a sliding scale related to the proportion of removable dirt contained in the coal. A simple method is shown for determining the amount of removable dirt by the use of chloroform.

Some Notes on the Trend of Coal-Cleaning Practice. W. R. Chapman. (Paper read before the Leeds University Mining Society, Feb. 20, 1928; Colliery Guardian, 1928, Vol. 136, Mar. 16, pp. 1031-1032). Certain aspects of coal-cleaning practice are considered in the light of a comparison between wet and dry processes and of the use of coals cleaned by them.

Recent Advances in Utilisation and Beneficiation of Coal. J. F. Daniels. (Canadian Mining and Metallurgical Bulletin, 1928, Feb., pp. 282-287). Some of the salient features developed by research methods in the utilisation and beneficiation of coal are pointed out.

The Dry Preparation of Coal. H. Winkhaus. (Glückauf, 1928, Vol. 64, Jan. 7, pp. 1-13; Jan. 14, pp. 41-48). The history of the evolution of the dry cleaning of coal is related, a large number of dry cleaners are described, and their results in practice are recorded. A bibliography of forty references, of which thirty-seven are English, is appended.

Dry Cleaning of Coal for Carbonisation. C. H. W. Holmes. (Paper read before the Coke-Oven Managers' Association, Jan. 28, 1928: *Gas World*, Coking Section, 1928, Vol. 88, Mar. 3, pp. 32-39). The subject is discussed under the following headings: classification of coking slacks; relation between density and ash content; ash content and size of particles; coals capable of giving coke with 8 per cent. ash; and sulphur reduction. The application of pneumatic separation to the preparation of coking slacks is discussed at length.

The Dry Cleaning of Coal. A. N. H. Slade. (Paper read before the South Staffordshire and Warwickshire Institute of Mining Engineers: *Iron and Coal Trades Review*, 1928, Vol. 116, Apr. 20, pp. 567-568; *Colliery Guardian*, 1928, Vol. 136, Apr. 20, pp. 1544-1547). The author gives a general review of modern types of dry-cleaning plant. Factors which favour the adoption of pneumatic separation and ensure good results are: (1) absence of moist fines—below $\frac{1}{16}$ in.—from the raw coal; (2) convenient disposal of the dust collected; (3) efficient, large-capacity, non-clogging screens; (4) absence of flat scaly refuse particles; and (5) the presence of an appreciable proportion of dry and dirty fines—say, below $\frac{1}{8}$ in.—in the raw coal which could be extracted before the remainder of the coal goes to an existing washing plant, and thus lead to a considerably improved performance of the washer.

With correct design and supervision, spiral separators can be operated to give at one and the same time a coal containing not more than 2 per cent. of refuse and a refuse containing not more than 2 per cent. of coal, which represents exceedingly good separation. The following figures represent an actual typical test result on coal sized $\frac{7}{8}$ to $1\frac{1}{2}$ in.: Percentage weight of refuse picked out of clean coal, 1.18; percentage weight of coal picked out of the refuse, 1.4.

The Frazer and Yancey air-sand process will doubtless have a considerable application when the practical difficulties have been overcome. A comparison is also made of capacities, power consumption, and cost of various processes.

The Dry Cleaning of Durham Gas Coals. C. W. H. Holmes. (*Gas World*, Annual Coal Supplement, 1928, Vol. 88, May 12, pp. 23-26).

Pneumatic Separation of Small Coal. A. N. H. Slade. (*Colliery Engineering*, 1928, Vol. 5, Jan., pp. 7-9). The author describes the results of a series of tests on a variety of coals carried out at Birmingham University on a Birtley half-Wye air separator.

Coal-Picking and Conveying Appliances. J. W. Wardell. (*Colliery Engineering*, 1928, Vol. 5, Jan., pp. 27-30). Illustrated notes are given on the design and construction of coal-picking and conveying apparatus.

New Screening Plant at Shireoaks Colliery. (Iron and Coal Trades Review, 1927, Vol. 115, Nov. 25, pp. 783-784). The general arrangement of this coal-screening plant is illustrated and described.

The Cleaning of Coal. W. R. Chapman and R. A. Mott. (Fuel, 1927, Vol. 6, Oct., pp. 436-443; Nov., pp. 484-505; Dec., pp. 552-569). The continuation of a series of articles covering the entire range of modern coal washing and screening practice. Article XIX. (Oct.) describes different types of screens. Article XX. (Nov.) deals with miscellaneous washers, pumps, elevators, and conveyors; and in Article XXI. (Dec.) the economic advantages of coal cleaning are considered.

The Rheolaveur Coal-Washer in Belgium. H. Briggs and H. Louis. (Paper read before the Institution of Mining Engineers, Jan. 10: Iron and Coal Trades Review, 1928, Vol. 116, Jan. 13, pp. 48-49). The authors have examined a number of rheolaveur plants on the Continent, and describe ten washers in operation in Belgium.

A New Anthracite Cleaning Plant. (Colliery Engineering, 1928, Vol. 5, May, pp. 185-194). An illustrated account is given of the equipment of the screening and washing plants and the refuse-disposal ropeway recently erected at the Raven Colliery, South Wales.

Hindered-Settling Classification of Feed to Coal-Washing Tables. B. M. Bird and H. F. Yancey. (American Institute of Mining and Metallurgical Engineers, 1928, Technical Publication No. 76). The term "classification" is defined as the separation obtained when a bed of particles is held in a uniform state of suspension in an upward current of water, either continuous or pulsating, just sufficiently strong to keep the bed in a mobile condition. When the hindered-settling classifier is used with the coal-washing table the fine size raw coal, instead of being fed direct to tables, as is the prevailing practice, is first fed to the classifier and grouped, according to the rate of settling against the upward current of water, into perhaps six separate products. After dewatering, each of these except the sixth, a refuse product, is elevated to a special feed bin and washed on a separate table. The authors give a comparison of the results obtained with and without classification.

Retreating Middlings from Coal-Washing Tables by Hindered-Settling Classification. B. M. Bird and H. F. Yancey. (American Institute of Mining and Metallurgical Engineers, 1928, Technical Publication No. 77). Hydraulic classification has given the best results in the retreatment of table middlings. Instead of using the classifier to prepare the feed to the tables, as has been the practice in ore dressing, it is used to separate part of a middling product that cannot be retreated successfully on the table. There is always an incomplete separation of

washed coal from other products of the table, which makes desirable some form of retreatment of a middling product. Table middlings are characterised by the presence of free particles of coal and refuse, and by such relationship of size and specific gravity among these particles that the table alone cannot effect their separation. The retreatment of a middling in the hydraulic classifier increased markedly the yield of washed coal as compared with that of the table alone, and made it evident that the classifier might be applied with advantage in almost every table plant.

The Determination of the Washability of Coal. A. N. H. Slade. (*Colliery Engineering*, 1928, Vol. 5, Apr., pp. 141-144). A discussion of the float-and-sink method of investigating the washability of coal. The application of the float-and-sink method, method of conducting a float-and-sink analysis, flotation of the raw coal laboratory sample, methods of float-and-sink examination of dust and fines, fractional and cumulative float-and-sink analysis sheets, determination of inherent ash in coal and refuse, crushing coal with a view to improving its washability, and method of plotting washability curves are dealt with.

Recent Progress in the Technique of Coal Washing. C. Berthelot. (*Revue de l'Industrie Minérale*, 1928, Jan. 1, pp. 1-32). The continuation of a previous article (*see Journ. I. and S.I.*, 1927, No. II. p. 511). In the present instalment the general arrangement and operation of a coal washery are described, and details of the machines and systems of working employed are given. Consideration is also given to the economics of rheolaveurs and other coal-washing machines.

The Influence of the Removal of Clay from the Water Circulating in Washeries on the Ash Contents of the Washed Coals. C. Berthelot. (*Génie Civil*, 1928, Vol. 92, Apr. 21, pp. 387-390; Apr. 28, pp. 404-408). The author first deals with the increased value of a coke, if it be made from a better washed coal. For the washing process to be improved the dirty wash water must be more completely freed from suspended matter than is usually done. This is difficult, because the last remaining fine solids are in colloidal solution and will not settle out fast enough. The author therefore turns to chemical agents to flocculate the suspension, and so make it settle quickly enough for decantation to be carried out. He discusses briefly the subject of colloidal solutions and those of their properties germane to the matter, describes two methods of desliming (Franz and Wunsch), and gives details of results obtained by them, showing the economic advantages obtained.

Wetting and its Measurement. E. F. Grieg. (*Fuel*, 1928, Vol. 7, Mar., pp. 136-138). A liquid is said to wet a powder or fabric when it coats the surface of the grains or fibres with a continuous film which of necessity fills the pores, but there are distinct degrees of wetness and

dryness. Very fine coal-dust containing up to 3 per cent. of moisture shows great reluctance to wetting by water, but will swallow up hydrocarbons with avidity. Yet there is every reason to believe that a good deal of the 3 per cent. of moisture is present as a film on the surface of the coal. A continuous weighing balance has been employed by the author to measure the penetration of a mass of coal-dust by a wetting liquid. The apparatus is illustrated, and the method of using it is fully described.

Achievements in Pulverised Fuel Firing. H. J. Van Eck. (Fuel Economist, 1927, Vol. 3, Oct., pp. 35-40).

Furnace Temperatures in Pulverised Fuel Firing. M. G. Wallace. (Fuel Economist, 1927, Vol. 3, Oct., pp. 40-43).

Combustion Chambers for Pulverised Fuel. P. Rosin. (Fuel Economist, 1927, Vol. 3, Nov., pp. 107-111; Dec., pp. 161-165).

Factors in Pulverised Fuel Firing Affecting Economical Combustion and Boiler Design. (Fuel Economist, 1928, Vol. 3, Mar., pp. 351-358).

Powdered Fuel, with Special Reference to South Wales. D. Wilson. (Fuel Economist, 1928, Vol. 3, Apr., pp. 435-443). The advantages of powdered fuel firing are dealt with and different types of apparatus are described.

Pulverised Fuel Statistics in Germany. (Fuel Economist, 1928, Vol. 3, Jan., pp. 228). Official information regarding the use of pulverised fuel in Germany for the year ending Mar. 31, 1927, shows an increase in the utilisation of coal in powdered form for the year of 24 per cent. The consumption of powdered fuel during the year amounted to 304,083 tons of brown-coal and 2,972,734 tons of black-coal.

The "Buell" System of Pulverised Coal Firing. G. E. K. Blythe. (Paper read before the Institution of Engineers and Shipbuilders in Scotland: Iron and Coal Trades Review, 1928, Vol. 116, Mar. 16, p. 377). Illustrated particulars are given of this type of burner. The air for combustion is supplied to the propelling air in three separate streams, two of them from a fan, and the third an induced flow from the stokehold. Ignition and combustion of the coal particles take place instantaneously, and a maximum flame temperature is developed.

The Combustion of Powdered Coal: The Influence of the Degree of Fineness of the Fuel Particles. B. Moore. (Paper read before the Institution of Chemical Engineers, Mar. 8, 1928: Iron and Coal Trades Review, 1928, Vol. 116, Mar. 16, p. 389). The degree of fineness of fuel particles is shown to affect considerably the rates of combustion, the

ignition properties, and combustible capacities of powdered coals, and the results indicate that there is a critical temperature and a critical degree of fineness at which the combustion of the particles becomes nearly instantaneous.

Pulverised Fuel for Collieries and Industrial Plants. J. Burns. (Paper read before the South Staffs. and Warwickshire Institute of Mining Engineers : Fuel, 1928, Vol. 7, Mar., pp. 138-140). The author deals generally with the conditions under which pulverised fuel can be successfully applied to steam raising. A table is given showing how the exposed surface of 1 cu. in. of coal increases with fineness of grinding. If 1 cu. in. is pulverised so that it will all pass through a 200-mesh sieve, it will make about 64 million particles. The average size of each particle will be a cube of about $\frac{1}{400}$ in. side, and the total surface thus becomes 2400 sq. in.

Some Thoughts on Coal Pulverisation. P. V. Vernon. (Engineer, 1928, Vol. 145, Feb. 17, pp. 176-177). A brief discussion of some of the problems in the pulverisation of coal.

Powdered Coal for Malleable Iron. (Iron Age, 1928, Vol. 121, Mar. 1, pp. 600-601). The application of pulverised coal to the firing of malleable iron furnaces as practised by the Eastern Malleable Iron Co., Naugatuck, Conn., is described and illustrated.

Auxiliary Fuel with Blast-Furnace Gas. F. H. Daniels. (Blast-Furnace and Steel Plant, 1928, Vol. 16, Jan., pp. 52-55). The electrification of steel plants is bringing about a great saving in the amount of fuel burned, the maintenance and labour costs, and general operating expenses. A great many plants are adopting pulverised coal as a secondary fuel, when there is a shortage in the blast-furnace gas supply. The author points out the advantages of the use of the unit system over the storage system in the utilisation of pulverised fuel. The general arrangement of a furnace designed to burn blast-furnace gas, with coal as the secondary fuel, is shown.

Auxiliary Coal Powder Firing for Cupolas. H. F. Lichte. (Die Giesserei, 1927, Vol. 14, Dec. 10, pp. 870-875). Coal-dust firing for foundry cupolas has proved very successful, the advantages gained being a considerable saving of coke, an increased output of the furnace, an increased temperature of the molten iron, reduced sulphur and carbon in the iron. The coal-dust is blown in by compressed air through tuyeres. Tables are given showing the comparative melting costs with and without the use of coal-dust.

Coal-Dust Firing, with Particular Reference to its Application in Foundry Furnaces. Beckmann. (Giesserei-Zeitung, 1928, Vol. 25,

Jan. 1, pp. 2-16). The author discusses the advantages and disadvantages of the various methods of firing furnaces, and describes the preparation of coal-dust and its use in various types of furnaces used in foundries.

Powdered Coal for Plate Mills. R. H. Irons. (Iron and Steel of Canada, 1928, Vol. 11, Jan., pp. 12-14). A description is given of the pulverised coal plant of the Central Iron and Steel Co., Harrisburg, Pa.

Furnace for the Simultaneous Combustion of both Coal-Dust and Gas. A. Sauermann. (Glückauf, 1928, Vol. 64, Apl. 28, pp. 525-531). The combustion of coal-dust in the ordinary way necessitates the use of large combustion chambers, which are expensive. The combustion of the dust can, however, be accelerated by the simultaneous combustion of gas. A suitable furnace designed along these lines for use in a fire-tube boiler is described and the results of tests are tabulated. In one set of tests in which the heat content in the gas and in the coal-dust were in the proportion of 1 to 2.74, the steam production reached the high value of 34 kg. per sq. m. of heating surface. In another series where the heat content proportion was 1 to 3.82, 29 kg. per sq. mm. was obtained, and the combustion of the fuels appeared to be fairly complete. These results were improved upon by alterations of the burners and also by the introduction of means for keeping the fire tubes clean.

The Drying of Pulverised Fuels. P. Rosin and E. Rammeler. (Braunkohle, 1927, Vol. 26, June 25, pp. 261-268; July 2, pp. 286-293). The Vamico pulveriser, which effects the drying and pulverising operations in one machine, is described. The separation of the crushed and insufficiently crushed particles is brought about by hot inert gases (furnace waste gases), which therefore dries the fuel at the same time. A cyclone separator collects the fuel powder from the gas.

COKE.

The British Coking Industry and some of its Products. R. Ray. (Journal of the Institute of Fuel, 1928, Vol. 1, Apr., pp. 220-233). The author discusses a number of points illustrating the necessity for modernisation of the coking industry, and points out the economies to be effected by the co-ordination and centralisation of coking plants. Further economies could be made by the production of a more suitable coke for both blast-furnace and domestic use, and by the utilisation to better advantage of certain of the by-products of the coking process.

The Scope of the By-Product Coking Industry. C. P. Finn. (Paper read before the Carbonisation Conference, Feb., 1928: *Gas Journal*, 1928, Feb. 14, Special Number, pp. 43-45; *Gas World*, 1928, Vol. 88, Mar. 3, Coking Section, pp. 28-30). Practically all new by-product coke-oven plants erected during the last few years are constructed of high-grade silica brick and are worked at higher temperatures than was the old practice. The new ovens are of greater capacity and though usually narrower are higher than the average pre-war oven, and have a greater through-put per oven at a lower operating cost. Another feature is that the actual site of some of the larger plants is not at any particular colliery or steelworks; the deciding factor being the suitability of the site for the receipt of raw materials and for the disposal of gas. Coke-oven tar is to a great extent becoming the substitute for horizontal gas retort tar, the production of which has diminished as a result of the introduction of vertical retort practice. The use of coke-oven gas in internal combustion engines has not found as much favour as might be expected in view of the thermal efficiency of that type of prime-mover.

The By-Product Coke and Gas Industry. C. J. Ramsburg. (*Blast-Furnace and Steel Plant*, 1928, Vol. 16, Jan., pp. 28-29). During 1927 new by-product coking plants with an annual capacity of over 5 million tons were placed under construction or in operation in America. An important development has been the use of blast-furnace gas for heating the ovens. Considerable interest has also been aroused in the elimination of sulphur from the gas used in open-hearth furnaces. At the plant of the Central Alloy Steel Corporation a liquid purification plant for this purpose is in operation. This is the second plant to be put down for that purpose, the other being that of the Pittsburgh Steel Co., of Midland, Pa.

By-Product Coking Capacity. (*Iron Age*, 1928, Vol. 121, Jan. 26, pp. 268-269). A table is given showing the names of concerns operating coke-ovens in the United States, the number of ovens and the type. At the end of 1927 the ovens in operation and in course of construction had a capacity for carbonising 84 million net tons of coal annually, with an estimated yield of coke of $58\frac{1}{2}$ million tons. The total number of ovens built and in course of erection was 12,756.

The Piette Regenerative Coke-Oven. (*Iron and Coal Trades Review*, 1928, Vol. 116, Apr. 13, pp. 526-527). The design and construction of the Piette coke-oven are described and illustrated.

Modern Coke-Ovens and Coking Practice. E. Weise. (*Fuel Economist*, 1927, Vol. 3, Oct., pp. 55-57). An abridged translation of an article which appeared in *Feuerungstechnik*, Sept. 1 and 15, 1927.

The Influence of a Coke-Oven Plant in a Metallurgical Works on the Economy of Fuel. C. Berthelot. (*Génie Civil*, 1928, Vol. 92, Jan. 28, pp. 81-87; Feb. 4, pp. 107-110). The author illustrates and describes, in considerable detail, the coke-oven plant at the iron and steel works of the Société Metallurgique de Thy-le-Château, near Charleroi, Belgium. The works comprise blast-furnaces, steelworks, rolling-mills, &c.; and produce about 200,000 tons of steel. The author shows how the presence of the coke-oven plant in close proximity to the iron and steel works enables very considerable economies to be effected in the amount of fuel consumed.

Notes on Some Points of Coke-Oven Design. R. A. Mott. (Paper read before the Coke-Oven Managers' Association: *Gas World*, 1928, Vol. 88, Jan. 7, Coking Section, pp. 6-7). A brief discussion of the development of the hairpin flue in coke-oven design on the Continent.

Developments in Coke-Ovens. (*Gas World*, 1928, Vol. 88, Jan. 7, Coking Section, pp. 13-15). The article consists of communications from prominent coke-oven construction firms, giving particulars of their activities in the improvement of coke-oven design and operation.

Modern Coke-Oven Practice. G. J. Greenfield and G. H. Harrison. (Paper read before the Carbonisation Conference, Feb., 1928: *Gas Journal*, 1928, Feb. 14, Special Number, pp. 45-51). The authors show the present trend in regard to the design and operation of coke-ovens. The factors which influence the design of heating systems, and the principal lines upon which such design is progressing are described. The importance of operation by schedule and of the use of instruments and other devices for securing maximum efficiency is emphasised.

Study of Elements in Coal Carbonisation. F. M. Reiter. (*Heat-Treating and Forging*, 1928, Vol. 14, Mar., pp. 293-295). The distribution of elements throughout the distillation of coal is discussed and outlined in tabular form.

Means of Reducing the Coking Period and Increasing the Output of Coke-Ovens, by Modifying the Section of the Chamber and the Transport of Heat, in Various Types of Coke-Ovens. (*Feuerungstechnik*, 1927, Vol. 15, Sept. 1, pp. 283-285). A review of the principal means employed by German makers, Koppers, Otto, Collin, Still, to reduce the coking period and heat consumption, such as the reduction of the width and increases of height and length of the chambers, the use of silica bricks and the reduction of the path travelled by the hot gases. In the Koppers furnace the transverse conicity has been decreased.

The High-Temperature Carbonisation of Coal. Its Technical Evolution. C. Berthelot. (*Revue de Métallurgie, Mémoires*, 1927, Vol. 24, Oct., pp. 557-572). The author describes the evolution of the coal-carbonisation industry, from both the coke-oven and gasworks point of view. In the gasworks improvement has turned largely on the use of larger retorts, greater gas production per unit of coal, and the manufacture of better gas; in the coke-oven plant advances have been made along the following lines: various qualities of coal can now be used to produce metallurgical coke; ovens have been built of such sizes as to give the best results, both economically and technically; silica bricks are used in the construction of coke-ovens; mechanical handling is adopted; the ovens are provided with better doors; and "mixed" gases or water-gas are used to heat the ovens.

Influence of the Ash Constituents in the Carbonisation and Gasification of Coal. (Fuel, 1927, Vol. 6, Oct., pp. 449-472).

An Examination of the Influence of Various Factors on the Products of the Carbonisation of Coal. H. H. Thomas. (*Journal of the Society of Chemical Industry*, 1928, Vol. 47, pp. 77-83T).

The Uniform Heating of Coke-Ovens. G. E. Foxwell. (Fuel, 1927, Vol. 6, Oct., pp. 472-475).

Thermal Efficiency and Supervision of Coke-Ovens. K. Rummel. (*Glückauf*, 1927, Vol. 63, Dec. 10, pp. 1809-1817; *Archiv. für das Eisenhüttenwesen*, 1927, Vol. 1, No. 6, Dec., pp. 403-411, *Coke-Oven Practice Report No. 27 of the Verein Deutscher Eisenhüttenleute*). The author discusses the thermal conditions which occur in coke-ovens with regard to the running of the plant in the most efficient manner.

High-Pressure Process for the Manufacture of Synthetic Ammonia. F. Müller. (*Archiv. für das Eisenhüttenwesen*, 1928, Vol. 1, Feb., pp. 517-523). In 1913 about 85,000 tons of synthetic nitrates were produced, but in 1927 the world's annual production had risen to 514,000 tons; the ammonia annually produced at gas and coke works remains unchanged at about 345,000 tons, while Chilean nitrates, the sales of which were approximately 400,000 tons in 1913, show a decline in 1926-1927 to 200,000 tons. It would appear that the synthetic ammonia is gradually driving the Chilean nitrates off the principal markets. A descriptive review is given of the Haber-Bosch process, the Claude, the Casale, and the Mont-Cenis processes, and consideration is given to the practicability of making use, in these synthetic processes, of the large volumes of hydrogen contained in coke-oven gases, which may amount to 50 per cent. of such gases. The synthetic processes require about 2.5 cu. m. of hydrogen per kg. of nitrogen, and at present

this hydrogen is mostly obtained from water-gas derived from brown-coal.

The Synthesis of Ammonia from Coke-Oven Gas. T. Biddulph Smith. (Proceedings of the Cleveland Institution of Engineers, Session 1927-28, No. 4, pp. 109-138; Iron and Coal Trades Review, 1928, Vol. 116, Feb. 10, pp. 179-180; Feb. 17, pp. 222-223). The author deals with the synthesis of ammonia from coke-oven gas by fixation of the hydrogen with atmospheric nitrogen, and gives particulars of the plant at Douai, near Lille, where the Claude process is operated.

New Process for the Purification of Benzol. F. T. Hatswell. (Paper read before the Coke Oven Managers' Association, Dec. 12, 1927: Iron and Coal Trades Review, 1928, Vol. 116, Jan. 6, p. 74).

The Balance-Sheet of the Sulphur derived from the Coal in Coke-Oven Works. A. Weindel. (Brennstoff-Chemie, 1927, Vol. 8, Mar. 15, pp. 85-89). The removal of sulphur from coke-oven gas and from the coke is a process which must be carried out, but the value of the sulphur removed is not sufficient to compensate for the cost of its recovery.

Cooling Coke by the Dry Quench Process. C. Longenecker. (Blast-Furnace and Steel Plant, 1927, Vol. 15, Dec., pp. 580-581). A description of the Sulzer process, with operating results, is given.

Utilises Waste Heat of Coke. (Iron Trade Review, 1928, Vol. 82, Feb. 23, pp. 500-501). A short illustrated account of the Sulzer system of dry quenching coke.

The Fuel Problem. C. H. Lander. (Chemistry and Industry, 1928, Vol. 47, Jan. 27, p. 98). In a paper read before the Institution of Engineers and Shipbuilders, Glasgow, the author reviews the work carried out at the Fuel Research Station on the high and low temperature carbonisation of coal and also on the liquefaction of coal by the Bergius process (Berginisation).

The Relation between Low and High Temperature Carbonisation of Coal. A. Shimomura. (Fuel, 1928, Vol. 7, Mar., pp. 119-127). The investigation relates entirely to Japanese coals. Coals were carbonised up to 500° C., and the semi-coke was subjected to a further carbonisation up to 900° C. The yields and types of the cokes obtained were observed, and determinations were made of the amounts of water, tar, ammonia, and gas produced.

Synthetic Fuels : The Problem of the Rational Use of Mineral Fuels. (Chaleur et Industrie, 1928, Vol. 9, Mar., pp. 143-151). The author discusses the economic and industrial aspects of high-temperature and low-temperature carbonisation, direct hydrogenation of fuels, and the synthesis of fuels from the gases derived from the other processes.

A General Review of Low-Temperature Carbonisation. F. S. Sinnatt. (Paper read before the Carbonisation Conference, Feb., 1928 : Gas Journal, 1928, Feb. 14, Special Number, pp. 90-111). The author discusses the chief processes of low-temperature carbonisation, and gives particulars of those plants in this country which are in operation as large scale units, or are in course of erection. A great deal of information is also given showing the analyses of coal used at different plants, the percentage of solid residue obtained from the processes, together with the percentage of volatile matter present, the normal moisture found in air-dried cokes produced at various temperatures, calorific value of coals and low-temperature cokes, yield and composition of the tars, and yield of gas. In an appendix are listed the replies received from different plants in answer to a questionnaire.

The Chemical Study of Processes Involving the Carbonisation of Coal by Internal Heating. M. W. Travers. (Journal of the Institute of Fuel, 1928, Vol. 1, Apr., pp. 272-278).

Some Facts Regarding the Low-Temperature Carbonisation of Coal. G. S. Haslam and R. V. Wheeler. (Paper read before the Midland Institute of Mining Engineers, Mar. 23, 1928 : Colliery Guardian, 1928, Vol. 136, Mar. 30, pp. 1229-1232; Iron and Coal Trades Review, 1928, Vol. 116, Mar. 30, pp. 457-458).

Low-Temperature Carbonisation and the Boiler House. D. Brownlie. (Engineering and Boiler House Review, 1928, Vol. 41, Mar., pp. 411-415). A review of the present state of development in the efforts being made to combine the carbonising process with the combustion of fuel for steam generation. Reference is made to the following processes: Pintsch, Merz and McLellan, Wisner, Hanl, Salerni, McEwen-Runge, and Bartling.

Combined Low-Temperature Carbonisation and Combustion. D. Brownlie. (World Power, 1927, Vol. 8, Dec., pp. 301-309). Two outstanding defects of electricity station practice are loss due to latent heat in the condenser cooling water and combustion of raw coal under the boilers. The latter subject is dealt with from the point of view of a combination of low-temperature carbonisation and combustion, which submits the coal to suitable heat treatment in front of the boilers, separates liquid products, and burns both gas and fuel in

the combustion chambers. Latest practice in mechanical stoking and pulverised fuel operation is described.

Low-Temperature Distillation of Coal Briquettes. P. Weiss. (*Chimie et Industrie*, 1928, Vol. 19, Feb., pp. 195-204). After a brief historical survey of the development of low-temperature distillation, the author describes the experiments carried out and the results obtained by the *Compagnie des Mines de Vicoigne, Nœux et Drocourt*, in the production of solid smokeless fuel, using briquettes of coals of various kinds as raw material. The briquettes are placed in a series of specially arranged chambers heated internally by superheated steam; the steam passes always in the same direction through the series of chambers, but its point of entry is periodically changed so that each chamber is in turn heated to the maximum working temperature. The distillation products are of high value, and the dense briquettes of smokeless fuel are immediately utilisable and commercially paying.

The Application of Low-Temperature Carbonisation to Gas-Producer Practice. S. Uchida. (*Fuel*, 1928, Vol. 7, Apr., pp. 179-185). Some experiments carried out in Japan with domestic fuel are described.

Composition of Tar from Low-Temperature Carbonisation of Utah Coal. R. L. Brown and B. F. Branting. (*Industrial and Engineering Chemistry*, 1928, Vol. 20, Apr., pp. 392-396).

The Utilisation of Lignite, in Particular by the Kohlenveredlung Carbonisation Process. M. Dolch. (*Braunkohle*, 1926, Vol. 25, Sept. 18, pp. 606-612; Sept. 25, pp. 627-632). The author draws attention to the fact that in the semi-carbonisation of fat coals, producing 10 per cent. of primary tar, the latter represents 33 per cent. of the calorific power of the raw coal, and the coke 52 per cent. In the case of brown lignite the proportions are 19 and 65 per cent., and with bituminous coals 12 and 74 per cent. The cost of carbonisation is given, and from these data a balance-sheet for the semi-carbonisation of coals and lignites may be prepared.

The Carbonisation of Coal with Waste Gases by the Lurgi Process. O. Hubmann. (*Braunkohle*, 1926, Vol. 25, Nov. 27, pp. 802-807). This process is intended for use with very wet lignites. The gas produced by the coking of the lignite (previously dried) in the retort is used to dry more lignite in the dryer as well as to supply some of the heat required by the retort. The end products are semi-coke and primary tar.

The C.T.G. Carbonisation Process (Chemisch-Technische Gesellschaft m.b.H., Duisburg). A. Spilker. (*Brennstoff-Chemie*, 1927, Vol. 8, June 15, pp. 183-187).

The K.S.G. Low-Temperature Process. J. N. Hazeldon. (Fuel, 1928, Vol. 7, Apr., pp. 155-160). This process of coal carbonisation is being operated at Karnap, near Essen. The present plant was built in 1924, and has been in practically continuous operation since that date, over 50,000 tons of coal having been successfully carbonised. The construction of the retorts, the heating system, the feeding of the coal and the manner in which carbonisation proceeds, the gas and tar recovery, and the heat and power requirements are described.

The Products obtained by the Laing and Nielsen Process. H. Nielsen. (Brennstoff-Chemie, 1927, Vol. 8, June 15, pp. 190-192).

Low-Temperature Carbonisation. F. Schwerts. (Chimie et Industrie, 1928, Vol. 19, Apr., pp. 583-588). The article deals with the Salerni low-temperature carbonisation plant and its application in special cases.

The MacLaurin Smokeless-Fuel Plant at Glasgow. (Engineering, 1928, Vol. 125, Feb. 3, pp. 128-129). An illustrated account is given of this plant, which has been in operation at the Dalmarnock Gasworks of the Glasgow Corporation since October, 1925.

Low-Temperature Carbonisation of Bituminous Coals. (Gas World, Annual Coal Supplement, 1928, Vol. 88, May 12, pp. 26-27). The results are reported of tests, carried out by the Director of Fuel Research, on a unit Crozier retort of the continuously working vertical type.

The Turner Process of Low-Temperature Carbonisation. C. Turner. (Journal of the West of Scotland Iron and Steel Institute, Session 1927-28, Vol. 35, Pt. 3, pp. 22-33). The author describes the Turner low-temperature carbonisation plant at Coalburn, Lanarkshire, and gives particulars of some operating results.

A New Coking Process. (Fuel Economist, 1927, Vol. 3, Dec., pp. 185-186). Particulars are given of a process developed by Parr and Layng for the carbonisation of coals outside the range of the usual coking coals. Coal is crushed down to pea size, and passes through a preheater where it undergoes the first stage of carbonisation. The coking oven is of the horizontal recuperative coke-oven type, fired with producer-gas. The preheater is heated by the waste heat from the flue gases, after these have passed through the heating flues of the oven. The coal attains a temperature of about 300° in the preheater, which temperature is retained, as far as possible, until the coal is charged into the coking oven. The preheating effects three purposes which constitute the essential advantages of the system: the moisture is removed from the coal; the oxygen is also removed from the coal in the form of carbon dioxide, and the coal which is charged to the coking oven is already partially heated. The result is to shorten

considerably the coking period, while the removal of the oxygen makes it possible to use coal that cannot be coked by ordinary coking processes.

New Low-Temperature Carbonisation Process. (Colliery Guardian, 1928, Vol. 136, Feb. 3, p. 440). A brief illustrated account extracted from a recent number of "La Technique Moderne" of the Bonnevie low-temperature carbonisation furnace. The furnace is formed of a series of horizontal retorts having internal mixers and placed vertically one above the other. They thus form a kind of fractional distillation column in superposed stages and at a gradually increasing distance from the source of heat. This arrangement makes for thorough carbonisation of the fuel treated and the direct fractional distillation of the by-products. The mechanical stirring arrangement inside facilitates transmission of the heat to the coal and promotes distillation.

Blending in the Gas and Coke Oven Industries. J. Roberts. (Paper read before the Carbonising Conference, Feb., 1928: Gas Journal, 1928, vol. 181, Feb. 14, Special Number, pp. 85-90). The author describes briefly what takes place when a coking coal is subjected to heat treatment. He points out the advantages of blending, and discusses the principles involved in blending at coke-ovens and gasworks. Dewatering and de-ashing of coal are also dealt with briefly.

The Effect of Coal Segregation, Mixing, and Heating upon the Quality of Metallurgical Coke. F. F. Marquard. (Paper read before the American Iron and Steel Institute, May 25, 1928). The author describes the investigations carried out at the Clairton plant of the Carnegie Steel Co. to determine the best methods for the selection and preparation of coal for the production of a good quality metallurgical coke. The mixture of high volatile coal with as little as 15 per cent. of low volatile coal produces a hard coke much desired for blast-furnace work, but the increased cost of production outweighs the saving effected in coke consumption. Attention was directed towards the production of a good coke from 100 per cent. high volatile Pittsburgh coal. This was accomplished by mixing only such coals from the same seam and having the same melting characteristics, by removal of slate from the coal, by crushing to pass a $3\frac{1}{2}$ -in. screen, by the use of compartment bunkers to prevent segregation of lumps and fines, by uniform heating and coking at 2075° F. and over, by efficient quenching with resulting moisture in the coke averaging below $2\frac{1}{2}$ per cent. and very thorough screening and sizing of the coke.

A Differential Index of the Coking Power of Coal. A. W. Coffman and T. E. Layng. (Industrial and Engineering Chemistry, 1928, Vol. 20, Feb., pp. 165-170). By the use of the softening and solidification point determination test previously described by Layng and Hathorne, 1928—i.

the authors have arrived at a graphical means of determining for any coal an index number called the agglutinating index. The relative magnitude of this agglutinating index and the distribution of the area beneath the "time- dp/dt " curve indicates the manner in which coking energy and agglutinating power is distributed in coal. The state of weathering through which coal has passed may be determined by the value of the agglutinating index. It has also been shown that the agglutinating power of a coal is a function of (1) the rate of heating to which it has been subjected; (2) the conditioning to which it has been subjected; (3) the weathering through which it has passed; and (4) the chemical interactions taking place during plasticity. Under the test conditions stated, to produce coke coals must have an agglutinating index of 20 or more.

The Coking Property of American Coals. W. H. Fulweiler and T. K. Cleveland. (Paper read before the American Gas Association: Fuels and Furnaces, 1927, Vol. 5, Dec., pp. 1657-1658). The authors discuss the factors influencing the coking power of coal, and deal with methods of testing to determine this property.

Investigation of the Cokeability of the Structural Constituents of Bituminous Banded Coals from the Ruhr District. R. Kattwinkel. (Glückauf, 1928, Vol. 64, Jan. 21, pp. 78-83). The structural constituents of the bituminous banded coals from the Ruhr district were tested by thermo-chemical means; their cokeability was determined by crucible tests, and by the determination of the caking power of mixtures of the various constituents. The properties of the various constituents and their behaviour when mixed with one another are described and discussed.

Coke Research in the Iron and Steel Industry. E. C. Evans. (Paper read before the Carbonisation Conference, Feb., 1928: Gas Journal, 1928, Feb. 14, Special Number, pp. 51-56; see also this Journal, p. 53).

Coke and the Blast-Furnace. A. E. Taylor. (Paper read before the Coke-Oven Managers' Association: Gas World, 1928, Vol. 88, Feb. 4, Coking Section, pp. 18-20). The author has summarised conclusions reached by various investigators on the combustion of coke. Korevaar maintains that combustibility is governed by a number of factors, such as carbon surface, porosity, ash content, and the intrinsic activity of the carbon, the last of which he explains as being the reaction velocity of carbon and air per unit carbon surface at a definite temperature and under standard conditions of oxygen concentration and air pressure. He concludes that the volume of the zone of combustion is a measure of the combustibility under various conditions. His views on the effect of combustibility on furnace operation are such

that he supports the concentration of heat theory and rejects the re-oxidation theory. The concentration of heat theory is partially supported by Howland, whose views, however, do not comply with Grüner's ideal. Koppers maintains that the volatile content of the coke is an indication of its combustibility, that is, the higher the volatile content, the lower the temperatures of carbonisation and the greater the combustibility, and, incidentally, the lower the consumption per unit of pig iron. Sherman and Kinney conclude that such features as character of coal, coking process, coking time, density, porosity, and volatile content have no apparent material relation to the combustibility as measured in the experimental furnace or in the blast-furnace hearth. Hauser concludes that conditions of coking and width of oven have no influence on combustibility, but in ovens of equal width cokes made in a shorter coking period at a higher temperature show better combustibility than those in which the period of distillation is prolonged. The most economical coke is of moderate size, with high resistance to breaking and abrasion. The breaking resistance is materially reduced in narrow ovens, while the oven width has no effect on the resistance to abrasion. Arend and Wagner define the term reactivity and render it distinct from combustibility, though to some extent associated. They define it as a measure of the ease with which coke reduces carbon dioxide according to the equation $C + CO_2 = 2CO$. Their conclusion is that to reduce consumption the reactivity between 500° and 1100° C. must be reduced, which causes a lower percentage of CO to be present in the blast-furnace gas. They entirely refute the re-oxidation theory. From these different opinions there appears to be a balance in favour of a coke of high combustibility. On the other hand, there is a diversity of opinion as to whether the chemical and physical factors—namely, character of coal, coking process, coking time, density, porosity, and volatile content—have any material effect upon the combustibility.

The Reactivity of Coke. J. H. Jones, J. G. King, and F. S. Sinnatt. (Paper read before the Iron and Steel Institute, Annual Meeting, May 1928: this Journal, p. 145).

The Reactivity of Coke. J. H. Jones, J. G. King, and F. S. Sinnatt. (Department of Scientific and Industrial Research, Fuel Research, Technical Paper No. 18: Gas World, 1928, Vol. 88, Feb. 4, Coking Section, pp. 24-26).

Reactivity and the Uses of Coke. G. Agde. (Fuel Economist, 1928, Vol. 3, Jan., pp. 243-245). An abridged translation of an article which appeared in *Feuerungstechnik*, Oct. 15, 1927, pp. 301-304.

The Reactivity of Coke and a New Method of Determining It. R. A. Dengg. (Polytechnisch Weekblad, 1926, Vol. 20, p. 246; Fuel

1928, Vol. 7, Apr., pp. 152-154). An apparatus is described for determining the relative reactivity of different kinds of coke. Three kinds of coke were investigated, and from the results it appears that the reactivity of a given kind of coke, with respect to carbon dioxide formation, differs considerably at different temperatures, and further that, at the same temperature, different kinds of coke differ from one another in their reactivity with respect to carbon dioxide formation. Anthracite appeared to have the least reactivity, coking coal a great reactivity, and gas coal the greatest reactivity.

The difference between reactivity and combustibility is again emphasised, and an explanation is again offered as to why anthracite, though possessing the smallest reactivity, may have a very great combustibility. The experiments are being continued.

The Reactivity of Coke Towards Steam. G. A. Brender à Brandis and J. W. Le Nobel. (Het-Gas, 1927, Vol. 47, Mar. 1, pp. 154-159). The reactivity of coke towards steam parallels that towards carbon dioxide or towards air. In the production of water-gas CO_2 is always formed first, whatever the temperature; the CO is derived from the decomposition of the CO_2 by the coke. Gas coke is more suitable for making water-gas than metallurgical coke.

The Speed of Combustion of Coke. G. A. Brender à Brandis and J. W. Le Nobel. (Het-Gas, 1927, Vol. 47, Apr. 15, pp. 250-254). The authors describe their apparatus for determining the velocity of coke combustion, and discuss the results obtained with eight various samples. They confirm the observation made in practice that English coals often burn more rapidly than German coals. Metallurgical coke burnt slowly at the experimental temperature (600°C.), which was purposely kept low, as it was thought that the differences between the various cokes would be more clearly revealed than at higher temperatures.

Correlation of Physical and Chemical Properties of Cokes with their Value in Metallurgical Processes. W. T. K. Braunscholtz and H. V. A. Briscoe. (Paper read before the Coke-Oven Managers' Association: Gas World, 1928, Vol. 88, May 5, Coking Section, pp. 63-67). The work described in this paper was carried out in the laboratory of the Northern Coke Research Committee at Armstrong College, Newcastle, and represents the beginnings of an attempt to correlate certain of the more salient properties of cokes with their blast-furnace value. The procedure adopted in sampling coke is outlined, and the results of shatter tests are included. The following series of tests was made with the object of determining the influence of varying the manipulative details of the test one at a time on the results obtained: (a) influence of weight of coke taken in the shatter test; (b) influence of size of

shatter machine box on the shatter index; (c) influence of repeated shattering on the shatter index; (d) average weight of pieces of coke after shatter test. The results are also included of combustibility experiments, specific gravities, porosities and water absorption determinations, and coking tests of coal in tins (box tests).

Progress in Research on the Properties of Coke for Blast-Furnace Use. R. A. Mott. (Paper read before the Coke-Oven Managers' Association: Gas World, Coking Section, 1928, Vol. 88, Apr. 7, pp. 44-49). Notwithstanding developments in oven design and in operation of coke-oven plants, comparatively little attention has been paid to the improvement of the quality of the coke. Two factors have received some attention—namely, the fineness of grinding the coal charged to the ovens and the rate of heating employed in the coking. An outline is given of the procedure adopted at Sheffield University for testing a number of cokes and to determine their manner of burning under blast-furnace conditions.

The Mechanical Strength of Coke. G. Dörflinger. (Stahl und Eisen, 1927, Vol. 47, Nov. 3, pp. 1867-1871). A description of the "Micum-Drum," an apparatus which the author recommends as suitable for testing the strength of coke and resistance to disintegration.

Methods of Testing Strength of Coke. W. Wolf. (Stahl und Eisen, 1928, Vol. 48, Jan. 12, pp. 33-38). In view of the increasing stringency as to quality and uniformity of pig iron, the question of testing the qualities of blast-furnace coke becomes more and more acute. The mechanical action to which coke is subjected in the drum test is totally different from that to which it is exposed in sinking down in the furnace. A new method of testing is devised to resemble the conditions in the furnace. The apparatus consists of a vertically mounted steel cylinder of about 11 cu. ft. capacity, tapered for the lower 12 in. of its length. The open tapered lower end is fitted with a hinged trap-door held against the opening by an adjustable balance weight. The cylinder is filled with a given volume of coke and a plunger presses it down, wedging it through the contracted part, until the trap is forced open by the pressure. The taper is at such an angle that good hard coke thrown loose into the cylinder should be capable of being pressed through the contracted part without suffering much loss by abrasion. The pressure on the plunger is adjusted to 25 up to 30 lb. per sq. in. The measure of the softness of the coke is the percentage lost by abrasion, and charts are given showing the loss for various cokes, also showing that in the case of ovens delivering too soft a coke, the coking practice can at once be controlled to produce a harder one. The coke is screened after passing the cylinder, and good average coke should not lose more than 4 per cent. of its weight in the test. The test

conditions resemble those of the sinking down of the burden in the furnace. The samples of coke are taken by volume, and a chart shows the fluctuation in the weight of different cokes of the same volume. Another chart shows the effect of the degree of coke hardness on blast pressure and weight of ore charged, *i.e.* how the furnace slows up when the coke crumbles too much.

Improved Process for Testing the Strength of Blast-Furnace Coke. W. Wolf. (Fuel Economist, 1928, Vol. 3, Apr., pp. 466-469). An English abstract of the above article.

Manufacture of Metallurgical Coke, Gas Coke, and Low-Temperature Coke from Caking Coal. M. Dolch and E. Rindtorff. (Glückauf, 1928, Vol. 64, Mar. 10, pp. 301-309). A comparison is made of the composition and calorific value of these three classes of coke. Of the low-temperature cokes examined, one was manufactured by the K.S.G. process (Kohlenscheidungs Gesellschaft), the other was the produce of the C.T.G. process (Chemisch-Technische Gesellschaft). As is commonly known, the chief difference between the low-temperature coke and the other classes consists in the much larger proportion of volatile constituents in the former. The gases distilled from coke at high temperature consist essentially of hydrogen and carbon monoxide, whereas the gas from low-temperature coke contains considerable quantities of methane. The examination of thin polished specimens of coke shows that the density and structure of low-temperature coke differs very greatly according to the nature of the distillation process adopted

Coke for Crucible Steel Melting. R. V. Wheeler. (Fuel, 1928, Vol. 7, Apr., pp. 148-151). Crucible steel melters have a strong preference for the type of coke made in beehive ovens. They also differentiate between different beehive cokes with respect to qualities which, though difficult to define, are of undoubted importance to the melters. The requirements of the melters in respect to general properties of coke, mechanical properties, and manner of burning are stated, and the physical characteristics of coke, its general structure, porosity, combustibility, and the determination of these characteristics are discussed.

GASEOUS FUEL.

Gas-Producer giving Efficient Service. R. M. Chatterton. (Blast-Furnace and Steel Plant, 1927, Vol. 15, Dec., pp. 573-574, 581). A description of the Koller gas-producer is given. The producer body is stationary, the jacket and top being water-cooled. The grate revolves on three pairs of rollers running on a circular rail, and is constructed in

such a way as to adapt the producer to the use of low-grade fuels; spiral ribs are cast on the upper surface of the grate, and they serve to shear the bottom from the ash column and force it under the seal ring into the ashpit. The ribs also prevent the formation of chimneys in the fuel bed. Test results are recorded.

The Wollaston Producer Boiler. (Colliery Engineering, 1928, Vol. 5, Apr., pp. 158-160). Illustrated particulars are given of the Wollaston producer boiler for the utilisation of low-grade fuels. Producer-gas is generated in a producer and is burnt direct in vertical or horizontal boilers without loss of the sensible heat of the gas. One of the advantages of the producer furnace is its ability to burn inferior fuels containing a high percentage of ash and moisture. Particulars of test results are also included.

Gas-Producers with Cooling Jackets and Boilers. Gwosdz. (Die Giesserei, 1928, Vol. 15, Jan. 13, pp. 29-33). The author reviews briefly the development of gas-producers, and describes the construction of modern producers provided with cooling jackets and boilers for the production of steam. The advantages of the modern method of construction, in which iron plays a very large part, are indicated.

Observations on Gas-Producer Operation. V. Windett. (Proceedings of the Engineers' Society of Western Pennsylvania, 1928, Vol. 44, Feb., pp. 11-34). The paper contains the results of practical working tests carried out on 10 Wellman-Seaver-Morgan type L gas-producers operating in a glass factory. The author points out the similarities between the glass "tanks" (furnaces) and open-hearth steel furnaces, though the fuel requirements and heat conditions in the former are much more closely limited than in the latter. The author also considers briefly some points of producer operation.

Study of Complete Gasification. Note on an Apparatus producing a Gas with a High Calorific Power. M. Freyss. (Journal des Usines à Gas, 1927, Vol. 51, July 5, pp. 264-265). The "Kreisa" gas-producer consists of a producer surmounted by a distillation retort, two superheaters, and a waste-heat evaporator. One superheater supplies the steam feed for the producer, the other cracks the tars carried over by the gas. The calorific efficiency is 61.9 per cent., or, when taking account of the recovered tar, 66.9 per cent.

Automatic Hopper for Siemens and other Gas-Producers of Small Size. J. Sauvageot. (Chaleur et Industrie, 1927, Vol. 8, Dec., pp. 709-710). One difficulty encountered in the use of small producers is that every time a fresh quantity of coal is charged, a considerable quantity of volatile matter is liberated and is lost without being burnt. The middle portion of the hopper described is a cylinder divided into

compartments by four spiral partitions; it is closed at the top and bottom by discs carried on a vertical shaft. The discs have one 90° opening each, the latter being 180° apart. The lower end of the shaft carries a distributing blade. Rotation of the shaft by a simple variable gear allows each compartment to be filled in turn from the silo above, while the coal passes into the producer through the bottom disc opening without air or gas leakage. The quantity of coal in each charge is very small, so that the loss of volatiles mentioned above is reduced to a minimum.

Blast-Furnace Gas. G. W. Hewson. (*Fuel Economist*, 1928, Vol. 3, Feb., pp. 295-298). A discussion of some of the problems involved in the measurement of blast-furnace gas volumes.

A Comparison of the Most Important Methods Employed in the Cleaning of Blast-Furnace Gas. V. Harbord. (Paper read before the Iron and Steel Institute, Annual Meeting, May 1928: this Journal, p. 235).

The Cleaning of Blast-Furnace Gas. J. A. Boynton. (Paper read before the American Institute of Mining and Metallurgical Engineers, Feb. 1928: *Blast-Furnace and Steel Plant*, 1928, Vol. 16, Apr., pp. 482-486, 488). The paper opens with a brief discussion of the uses of blast-furnace gas. A number of important factors in gas washing are considered, and the disadvantages resulting from moisture in the gas are pointed out. All processes of gas cleaning, whether wet or dry, which contemplate practically complete cleaning, must include means for cooling the gas to the lowest practicable temperature, which will usually be below 90° F. At this temperature the maximum possible content of water vapour is 4.5 per cent., as compared with 10 per cent. or more in gas above the dew-point. Gas-cleaning practice in Germany is touched upon, and the advantages to be derived from fine cleaning are briefly discussed. The author also deals with the economics of the use of blast-furnace gas.

Electrical Precipitation of Dust Containing Metals from Industrial Gases. W. Deutsch. (*Zeitschrift für Metallkunde*, 1928, Vol. 20, Jan., pp. 25-27). The electrostatic precipitation of dust from gases in an apparatus of the plate type is described.

Flue-Dust Recovery. H. W. C. Henderson. (*World Power*, 1928, Vol. 9, May, pp. 284-289; June, pp. 340-347). The article describes the application of electrical flue-dust precipitation to powdered fuel installations, to blast-furnace and coke-oven plants, to the cleaning of sulphur dioxide gases in the acid industry, and to plants working in conjunction with smelting processes, alumina calcining, and cement kilns.

Electrical Cleaning of Gas on a Large Scale by the Elga System at Witkowitz. R. Durrer. (Stahl und Eisen, 1927, Vol. 47, Nov. 17, pp. 1933-1939; *abridged translation*, Fuel Economist, 1928, Vol. 3, Mar., pp. 361-362). An illustrated description is presented of a large electrostatic gas-cleaning plant on the Elga system, lately installed at Witkowitz. The plant is of a capacity to deal with 40,000 cu. m. per hr., and was the first of its particular kind to be erected. Results of tests are given, which show that a degree of cleanness can be obtained by the electrostatic method equal to that given by any other gas-cleaning method, while the working costs are distinctly lower than those of wet cleaning. The results obtained at Witkowitz are so satisfactory that another plant is now in contemplation for dealing with 240,000 cu. m. per hr.

Electrical Gas Cleaning. F. Brauneis. (Montanistische Rundschau, 1928, Vol. 20, Apr. 1, pp. 198-202). The principles of electrical gas cleaning and various types of plant are briefly described, and the advantages of the process and difficulties that have had to be overcome are discussed. In comparison with other methods of cleaning it is stated that the electrical power consumption for cleaning 1000 cu. m. of gas down to 0.01 gm. per cu. m. by wet processes amounts to 5 to 6 kw., by dry cleaning (filter) to $2\frac{1}{2}$ to 3 kw., and by the electrical cleaning, including auxiliary machinery, to about 1.5 kw.

Electrical Tar Extraction by the Cottrell-Moller Process. J. Weyl. (Sprechsaal, 1927, Vol. 60, June 2, pp. 388-392). An electrical tar extractor capable of treating up to 180,000 cu. m. per 24 hrs. is described. The process is carried out at a temperature (80° - 90° C.) above the dew-point of the gases, which results in the separation of the tar practically free from water, even when treating very moist gases, such as those from a coke-oven or from the distillation of lignite. The power required is about 1.8 kw.-hr. per 1000 cu. m. at N.T.P.

Extraction of Tar from Producer-Gas. (Fuel Economist, 1927, Vol. 3, Nov., pp. 126-130). An illustrated account is given of the Smith tar extractor, which has found wide application in America for cleaning producer-gas. The principle of operation involves passing the gas through a diaphragm of spun glass, or glass wool, under a few pounds pressure, not with the object of filtering out the tar, but of causing the particles of the tar-fog to combine and form particles too large to be held in suspension by the gas. The efficiency of the extractor under suitable conditions is as high as 99.5 per cent.

Tests on the Dry Purification (of Gas) at the Terres Rouges Works, Esch. M. Steffes. (Revue Technique Luxembourgeoise, 1928, Vol. 20, Mar.-Apr., pp. 34-39). The blast-furnace gas dry-cleaning plant consists of four filter units, each of a capacity of 40,000 cu. m. of moist gas

per hr. ; two further units are in course of construction. The hourly capacity of two disintegrators already in existence is 55,000 cu. m. of dry gas each, so that the total capacity of the Esch Works will eventually amount to 325,000 cu. m. per hr. This cleaning plant will be sufficient to purify the gas derived from the production of 1700 metric tons of pig iron per day ; there will then be in reserve two Zschocke fans.

Dry-Cleaning of Gases. R. Geipert. (Gas- und Wasserfach, 1928, Vol. 71, Jan. 28, p. 76). The author describes the process of desulphurisation of coal-gas by means of iron hydroxide.

Simultaneous Purification of Gas from Ammonia and Sulphuretted Hydrogen. H. Bähr. (Gas- und Wasserfach, 1928, pp. 169-173, 204-210 ; *abstr.*, Gas World, 1928, Vol. 88, Apr. 28, pp. 414-415). The author describes the development of the Burkheiser process, with its recent developments, the Walter Feld process, and gives details of a new catalytic process of his own invention. In this process, the crude gas is mixed with the requisite amount of oxygen or air and is passed over a catalyst ; the SO_2 produced immediately combines with the ammonia in the gas, forming ammonium sulphite directly.

Partial Drying of Town's Gas. C. Harris. (Paper read before the Southern Association of Gas Engineers and Managers, Nov. 1927 : Gas World, 1927, Vol. 87, Nov. 19, pp. 474-481 ; Gas Journal, 1927, Vol. 180, Nov. 23, pp. 529-535). The "Dri-Gas" process is described. A 40 per cent. solution of calcium chloride is used as the drying agent ; a stronger solution cannot be used, as crystals of $\text{CaCl}_2 \cdot 6\text{H}_2\text{O}$ are formed at higher concentrations at ordinary temperatures. The solution is pumped into a Holmes patent rotary brush scrubber, where it picks up all the moisture in suspension in the gas, and about two-thirds of the moisture present as water vapour ; it becomes heated and diluted in the process, and overflows into the stock tank. This solution is constantly recirculated, but after passing through the cooler about 5 per cent. is drawn off and run over an evaporator while the remainder feeds into the washer. The concentrated liquid flows into the stock tank, so that over-evaporation, should it occur, is immaterial. Ammonia in the gas, if any, causes the deposition of calcium carbonate, but the growth is slow and the scale is easily removed from the evaporator. The cost of cleaning is estimated at 0.231d. per 1000 cu. ft., if a million cu. ft. are cleaned daily ; on a 5 million per day unit the cost would be about 0.15d. per 1000 cu. ft. (capital charges and depreciation included).

Experience with Total Gasification. K. Bunte. (Gas- und Wasserfach, 1927, Vol. 70, June 18, pp. 617-621). The author considers that complete gasification and the long-distance distribution of coke-oven gas are opposed to the development of the supply of gas, because while increasing the amount of gas available they do not increase the amount

of gas coke available. He is of opinion that in countries with large metallurgical industries, like England and Germany, the complete gasification process will not develop very greatly, and will only be applied to the adjustment of local equilibrium between the production of gas and coke. The article gives the results of an experimental test made at the Weisenau works, built by the Gesellschaft für restlose Vergasung in Nordhausen, the plant of which is described. The results demonstrate the importance of the heat losses which may occur by radiation and conduction.

Technical Problems in Long-Distance Transmission of Gas. F. Baum. (Stahl und Eisen, 1928, Vol. 48, Feb. 9, pp. 161-170). The Coal Utilisation Co., Ltd., is an organisation founded with a backing of 90 per cent. of the Rhenish-Westfalian Coalowners with the object of developing independently the liquefaction of coal, the manufacture of nitrogen, and supply of industrial gas to large parts of Germany. Many obstacles to long-distance supply of gas have had to be overcome. The State railways have demanded a levy per cu. m. of gas in compensation for loss of freight, towns in which works of prospective customers are situated claimed octroi duties, and owners of way-leaves had to be satisfied. The position is that some 200 million tons of coke are produced annually to meet industrial needs, and there are some 9000 million cu. m. of gas to dispose of, if the type of coke-oven heated by low-grade gas becomes universal, the adoption of which has already been largely carried through. The problem of marketing several grades of coal in proportion as these are raised from the mines is also now open to solution. Grades of coal which are unmarketable will be gasified, bituminous slack, and in fact all bituminous material, will be withdrawn from the market and will be replaced by lean and long flame coal. All this can be done without increasing the supply of metallurgical coke by 1 ton beyond what is necessary for industry.

The centre of gas supply is near Dortmund, and two main pipe lines have already been laid. One runs west to Essen, Krefeld, Düsseldorf, Remscheid, and Solingen, the other south-east to the Siegerland. It is hoped to carry the latter right through to South Germany. The mains are 800 mm. diam. ($31\frac{1}{2}$ in.) at the starting-point. For the west the gas is pumped in at a pressure of three atmospheres abs. The guaranteed consumption westwards is 200 million cu. m. a year, and it is expected this will soon reach 500 millions. Southwards and eastwards the gas is pumped at a pressure of five atmospheres abs., and the present prospective consumption is also 200 million cu. m.; but when extensions now in hand are complete a great increase is expected. For longer distances south of Nachrodt the pressure will be boosted up to 10 to 15 atmospheres abs. The cost of production of the gas is calculated at 1.8 to 1.9 pfennig per cu. m. (about $4\frac{3}{4}$ d. per 1000 cu. ft.), and its heat value is 4300 kg. cals. To the cost must be added that of cleaning, compression, and transmission. In the Dortmund area the basic sale price is fixed at

three pfennigs per cu. m. (about $9\frac{1}{4}$ d. per 1000 cu. ft.), but this is the price charged to the subsidiary local companies which take charge of the distribution in their area and may add a percentage depending on local conditions ; apparently the subsidiary company is under obligation to limit the surcharge to a maximum of 5 per cent. of the basic price.

The large mains are in general laid along the roads, but great trouble was at first experienced from vibration due to traffic and subsidence owing to mine workings. Leakages up to 20 per cent. occurred with the usual types of joint. Seamless steel tubes are now used, and those of large diameter are joined by water-gas welding. The pipes are placed in position, welded, and then lowered into the trench. Curves of 80 to 90 m. radius can be made by springing the pipe without using special curved pieces. A cable is laid with the pipe, containing telephone leads, and other leads for the automatic indicating of pressure and volume, so that the compressing station is kept instantly informed of what is happening down the line. Storage gas tanks are not yet contemplated, the pipe-line itself being a huge reservoir. The Sunday stoppage of collieries anyway assures a large weekly surplus which can be temporarily compressed in the mains.

The average composition of the gas is : $\text{CO}_2 = 2.4$, heavy hydrocarbons = 2.0, $\text{O} = 0.5$, $\text{CO} = 6.0$, $\text{H}_2 = 52.5$, methane = 25.3, $\text{N} = 11.3$ per cent. The following are the guaranteed conditions : Cal. value not less than 4300 kg. cal. per cu. m. ; the gas must be technically free from tar and absolutely free from sulphuretted hydrogen ; ammonia not to exceed 2 grm. per 100 cu. m. ; naphthaline not to exceed $\frac{10}{p}$ grm. per 100 cu. m. (p being the initial pressure in the mains) ; the sp. gr. of the gas in air shall not exceed 0.5 with allowance of ± 2 per cent. ; the oxygen shall not exceed 0.5 per cent. by vol. ; organic sulphur shall not exceed 25 grm. per 100 cu. m. ; the temperature at the admission end of the mains shall not exceed 30°C . The methods of metering are described, and some furnace installations using long-distance gas are illustrated, with descriptions and sections of special types of burners.

Theoretical and Practical Determination of the Pressure Drop in the New Gas Mains connecting the Arbed Works at Esch. M. Steffes. (Stahl und Eisen, 1928, Vol. 48, Apr. 5, pp. 441-444). Three new gas pipe-lines have been completed to connect the four works of the Arbed Company. The three lines diverge from the central works, Terres Rouges, Esch, to the other three works at Belval, Esch, and Oth. The dimensions are, to Belval, length 2650 m., and 1500 mm. diam. ; to Esch, length 2150 m., and 1500 mm. diam. ; to Oth, length 2500 m., and 1250 mm. diam. The pressure drop for given lengths and diameters was mathematically calculated beforehand according to the Ledoux formula, which is stated, and practical trials afterwards showed that the calculated results were fairly accurate. In the two pipe-lines of

1500 mm. diam. the drop in pressure from one end to the other varied from 20 mm. water-gauge with a flow of 20,000 cu. m. per hr. to 300 mm. water-gauge when the rate of flow was increased to 100,000 cu. m. per hr. In the line of 1250 mm. diameter the pressure drop was from 45 mm. water-gauge with a flow of 20,000 cu. m. per hr. to 300 mm. with 60,000 cu. m. per hr. Apparently the desired end pressure was 200 mm. water-gauge.

The Flow of Producer-Gas in Pipes. (Gas Age Record, Jan. 7, 1928; Heat Treating and Forging, 1928, Vol. 14, Feb., p. 198). Formulæ are given by which the dimensions of pipe-lines and mains for conveying producer-gas can be calculated.

The Flow of Gases in Mains and Culverts. W. Goldsbrough (Proceedings of the Cleveland Institution of Engineers, 1926-27, pp. 203-224).

The Gas Industry : Past, Present, and Future. W. J. A. Butterfield. (Paper read before the Carbonisation Conference, Feb. 1928; Gas Journal, 1928, Feb. 14, Special Number, pp. 17-26). According to the author, in certain parts of the country large quantities of coke-oven gas—about 2,322,000,000 cu. ft. in 1926—are being taken by gas undertakings from coke-oven works. The utilisation of coke-oven gas in this manner is increasing, and would increase at a far more rapid rate were it not for the uncertainty as to the continuity of such supplies of gas at times of labour difficulties at the collieries where the ovens are situated.

Utilisation of Coke-Oven Gas. F. White. (Paper read before the Coke-Oven Managers' Association: Iron and Coal Trades Review, 1928, Vol. 116, Jan. 6, p. 7). A brief discussion of the recent developments in the utilisation of coke-oven gas in Belgium and Germany. An outstanding feature is the enormous development of the transmission of gas over a very wide area and its utilisation for public lighting and industrial purposes.

Efficient Combustion of Blast-Furnace Gas. (Fuel Economist, 1928, Vol. 3, Jan., pp. 247-248). Illustrated particulars are given of the Brooke-Gough burner for blast-furnace gas, which has given excellent results at the works of Messrs. Lysaghts, Ltd., Scunthorpe.

Losses in the Exhaust of a Blast-Furnace Gas Engine. M. Steffes. (Stahl und Eisen, 1928, Vol. 48, Feb. 2, pp. 139-141). In the working of an internal combustion engine a large proportion of the total heat losses is due to the escape of unburnt gases along with the products of combustion in the exhaust. To determine the extent of the losses due to this cause, a waste-gas recorder should form an essential part of

the equipment for registering the efficiency of the gas engine and the work done within the cylinder. Trials were undertaken on a Cockerill gas engine at the Belval Terres Rouges works near Luxemburg. It was a double-acting 4-cycle tandem engine, giving 1875 H.P. at 80 r.p.m. In general, the most favourable combustion conditions occurred when the excess air volume was between 1.2 and 1.4 times the theoretical requirement, and further, with constant volume of excess air, the loss through escape of unburnt gas was lowest when the number of revolutions was lowest. The recorder should be capable of measuring not only the CO_2 but the CO and H_2 with sufficient accuracy. The results of the trials are fully tabulated and shown diagrammatically.

LIQUID FUEL.

Phenols in Petroleum Distillates. L. G. Story and R. D. Snow. (Industrial and Engineering Chemistry, 1928, Vol. 20, Apr., pp. 359-364). The authors have studied phenols separated from petroleum distillates. The larger quantity present in cracked distillates shows that the reaction producing these compounds occurs primarily in the cracking process. Results of the investigation indicate that the product is composed chiefly of high-boiling compounds, with very little or no carboic acid, but the cresols have been isolated and identified. A comparison is made of the petroleum phenols with those from other sources, and a resemblance to those from low-temperature carbonisation of coal is pointed out.

The Production and Uses of Petroleum Coke. L. O. Mekler. (Fuels and Furnaces, 1927, Vol. 5, Dec., pp. 1637-1640). The author discusses the operation of coking and cracking stills, and deals with the uses of petroleum coke.

Storage and Handling of Fuel Oil. J. R. Miller. (Heat Treating and Forging, 1928, Vol. 14, Mar., pp. 309-310).

Contribution to the Knowledge of "Berginisation" and a Study on the Technical Chemical Investigation of Hydrocarbon Mixtures. Part I. H. I. Waterman and J. N. J. Perquin. (Journal of the Institution of Petroleum Technologists, 1927, Vol. 13, pp. 413-423). This work is a continuation of an investigation (1925, Vol. 11, p. 48) on the nature of liquid reaction products obtained from the action of hydrogen on paraffin wax under high pressure.

Liquid Fuels other than Petroleum. A. E. Dunstan and H. G. Shatwell. (Journal of the Institute of Fuel, 1928, Vol. 1, Apr.,

pp. 262-271). The authors discuss the chief developments in the production of oil from coal.

The Conversion of Coal into Oil by the Bergius Method. J. I. Graham and D. G. Skinner. (*Journal of the Institute of Fuel*, 1928, Vol. 1, Apr., pp. 246-261). The authors review the present position of the process, and present the results of hydrogenation experiments on British coals, carried out in the Mining Research Laboratory of Birmingham University.

The Production of Liquid Fuels from Coal. R. H. Clark. (*Canadian Mining and Metallurgical Bulletin*, 1928, Feb., pp. 274-281). The paper considers briefly: (1) the production of primary tar by low-temperature carbonisation of coal; (2) the hydrogenation of coal; (3) the synthetic processes of Fischer.

Extracting Oils from Coal. (*Gas Journal*, 1928, Vol. 181, Jan. 18, pp. 145-146). A brief description of the Rational Carbonisation Syndicate, Ltd., two 5-ton retorts, working on the Dvorkovitz system, at Slough.

Coal Liquefaction and its Importance in World Economy. H. Bruckmann. (Paper read before the Deutsche Weltwirtschaftlichen Gesellschaft: *Mining Journal*, 1928, Vol. 160, Jan. 28, pp. 69-70; Feb. 4, p. 94; Feb. 11, p. 116).

The Dvorkovitz Low-Temperature Carbonisation System. (*Engineering*, 1928, Vol. 125, Jan. 20, pp. 72-73). An illustrated account is given of the Dvorkovitz carbonisation system. Its essential feature consists in supplementing the external heating of the retort with producer-gas, by introducing into the upper parts of the retort and of its downward extension, a supply of gas preheated to a moderate temperature. This gas flowing through the charge takes up and carries the oil vapour to outlets at the bottom, whence it is led together with the vapours to condensing, washing, and purifying plants. The coal is fed to the retort through hoppers. The evolution of the oil vapours and their absorption by the carrier gas is assisted by a spiral stirring arrangement. When the treatment in the upper part of the retort has proceeded sufficiently far, the charge passes through a valve into the lower part of the retort, where the distillation is continued under the influence of the external heat from the producer-gas. The carrier gas on leaving the retort returns to the lower part of the superheater coil, and circulates again through the retort as before. The capacity of the retort is $2\frac{1}{2}$ tons, and of the lower part 3 tons. The gas produced in the process is said to amount to from 3 to 6 per cent. of the charge.

Coal Carbonising to Produce Oil. (Colliery Engineering, 1928, Vol. 5, Feb., p. 70). Brief particulars are given of the Dvorkovitz experimental plant for the production of oil from coal. The main object of the process is to treat coal for the production of oil, leaving a residue of coke. The coke is friable, though it can be used for domestic fuel if required; it is mainly intended for industrial utilisation in the pulverised form.

Diesel Engine Performance on Oils obtained from the Low-Temperature Carbonisation of Coal. J. S. Brown. (Journal of the Royal Technical College, 1927, No. 4, Dec., pp. 76-84). This paper discusses an important aspect of the ultimate value of the oils now being obtained by subjecting coal to a low-temperature carbonisation treatment. Tests on a Diesel engine are quoted to show the difference in behaviour of these oils as compared with petroleum fuel oil. It is shown that the new oils may reach a standard where the only handicap is the necessity for preliminary heating of the engine prior to starting. The oils are definitely preferable to the creosote oils previously obtained from coal, and a little further improvement would give them all the properties of a petroleum oil.

Oil, Coal, and By-Products. W. Hunter. (Journal of the West of Scotland Iron and Steel Institute, 1927-28, Vol. 35, pp. 10-19).

PRODUCTION OF IRON.

PIG IRON.

Improvements in Blast-Furnace Construction. J. P. Dovel. (American Institute of Mining and Metallurgical Engineers, 1928, Technical Publication No. 73). The author points out that the expense of replacement and relining of a blast-furnace may consume all the profits made, and describes the various steps taken in altering the construction of a furnace so as to make it permanent. A permanent hearth was secured by making it of heavy cast-iron sections bound together with wrought iron bands. The whole bosh is encased in metal and does not depend on its brickwork to any extent. The oldest structure of this type has been in service for 11 years and is still in perfect condition. Failures in the inwall section above the mantle were dealt with by inserting a series of rows of bronze cooling plates from the outside, attached to and supported by the shell. Permanency of the top was attained by discarding the brick in the top section, substituting a heavy cast-steel jacket lined with cast-iron blocks, which withstands the wear and makes a permanent stock line, making possible the distribution of stock without regard to the brickwork, reducing flue-dust production, decreasing coke consumption, and increasing the capacity.

Low Cost Pig Iron Means Highest Output per Furnace. W. A. Haven. (Iron Age, 1928, Vol. 121, Feb. 2, pp. 334-335). The author discusses the trend in blast-furnace design and practice in America. Many old stacks have been reconstructed with larger hearths. Large hearth furnaces are stated to take a high blast temperature without difficulty, and their coke rates have been as good if not better than small units. A furnace was blown in during last year having a hearth diameter of 24 ft. 6 in. With a fair quality of raw materials the 24 ft. 6 in. furnace should easily produce 850 tons per day. By physical and chemical betterment of ore and coke this may be increased to 1000 tons daily. It is claimed that furnaces in Germany are producing more than 1000 tons daily, which has been accomplished chiefly by the use of sintered ore. During the past year a number of American works have put down plants for the sintering of flue-dust. The extreme dryness and fineness of this material has been the cause of much trouble in handling, and it has been overcome by watering the material in a dust-tight conveyor mixer as it passes from dust-catcher to car.

Proper cooling and moistening before reaching the sintering plant helps in the final hydrating before the dust reaches the sintering pan.

Progress in the Blast-Furnace Field. O. R. Rice. (Blast-Furnace and Steel Plant, 1928, Vol. 16, Jan., pp. 49, 55). A cursory survey of the improvements in furnace design and operation with reference to larger production; the average daily capacity is increased.

The Blast-Furnaces of the Mineral Basin of Lorraine-Luxemburg. A. Wagener. (Fuel Economist, 1928, Vol. 3, Feb., pp. 301-302; Mar., pp. 381-385; Apr., pp. 456-459). An abridged translation of an article which appeared in *Revue Technique Luxembourgeoise*, 1927, Vol. 19, June, Special Number, pp. 15-27, describing the present state of development of blast-furnace design and operation in this region.

German High-Tonnage Furnaces. F. H. Willcox. (Iron Age, 1928, Vol. 121, Apr. 12, pp. 1011-1012). Particulars are given of blast-furnace construction and practice in Germany. The German furnaces are as a rule much more massive than those in America. With regard to high tonnage furnaces some remarkable rates are being maintained in Germany. For instance, one plant produces 930 tons a day in a 22,300 cu. ft. furnace without outside scrap on a yield of 54 per cent. The blast volume is 120,000 cu. m. per hr. blown at 14-lb. pressure through eight tuyeres. The blast temperature is 1300° F. The coke rate is 2080 lb., and the top temperature is about 650° to 700° F. Low-silicon basic iron is produced and the slag runs 34 to 35 per cent. Si, 10 to 11 Al_2O_3 , 5 to 6 MgO , and 45 to 46 per cent. CaO , with sulphur about 1.5 to 2 per cent. The furnace is tapped from six to eight times a day, depending on the demands for the mixer.

A New Australian Blast-Furnace Plant. A. J. Ebner. (Freyn Design, Apr. 1928, No. 5, pp. 19-20). Particulars are given of the new blast-furnace in course of erection at Port Kembla, near Sydney. The furnace, which is owned by the Hoskins Iron and Steel Co., is being built to the following lines:

Height	86 ft. 2 in.
Hearth diameter	18 ft. 0 in.
Bosh diameter	12 ft. 6 in.
Bosh angle	80 deg. 5 min.
Stock line	15 ft. 3 in.

An unusual feature will be the cooling of the furnace by salt water. The gas will be washed in a stationary washer, and the stove gas will be subjected to further cleaning by a disintegrator. Three stoves are being built, each 21 ft. by 105 ft. and containing 68,700 sq. ft. of heating surface. The design of the furnace and equipment will conform to American practice.

Improvements in Blast-Furnace Equipment. A. Wagner. (Stahl und Eisen, 1928, Vol. 48, Feb. 9, pp. 181-182). An improved apparatus for closing the tap hole of blast-furnaces is illustrated and described. It consists of two cylinders lying one on top of the other which communicate in such a way that the rams in combination move alternately in and out and so prevent the risk of a blow-out. The machine is operated and slewed by remote control.

Closed Cooling-Boxes for Metallurgical Furnaces, particularly Blast-Furnaces. (Stahl und Eisen, 1928, Vol. 48, Jan. 5, p. 21). A fully illustrated description is given of a design of cooling-box for cooling the walls of furnaces, in which the disadvantages of both the closed box and open box are obviated. The new type of box is fitted with a small door and a peephole on the outside. This permits of cleaning out the box when necessary, and if leakage occurs on the inside wall the gas pressure in the furnace blows out water and steam which is immediately noticeable on the outside.

New Furnace Hoist at the South Bank Works of Messrs. Bolckow, Vaughan & Co., Ltd. (Iron and Coal Trades Review, 1928, Vol. 116, Jan. 13, pp. 33-34). The arrangement of the electrically driven vertical hoist serving the No. 7 blast-furnace at the South Bank Works of Bolckow, Vaughan & Co. is described and illustrated.

Improving Hot-Blast Stove Efficiencies. J. B. Fortune. (Paper read before the Institution of Mechanical Engineers: Iron and Coal Trades Review, 1927, Vol. 115, Dec. 9, pp. 857-859). The paper sets forth some results that have been obtained at the Margam Works of Messrs. Baldwins Ltd., in an endeavour to reduce the amount of gas used in the stoves. The blast-furnace plant consists of two mechanically charged furnaces, each having an output of about 350 tons of basic iron per day. Each furnace is equipped with five Cowper stoves 90 ft. high and 21 ft. in diameter. The gas supplied to the stoves is cleaned down to a dust content of 0.125 gm. per cu. m. in a Halberg-Beth cleaning plant. Of the five stoves three are on gas and two on blast at the same time. Each stove is kept on blast for an average period of 2 hrs., and on gas for an average of 3 hrs. Hourly and daily analyses of the cleaned gas for a period of several weeks gave the following average composition: CO 30.3, CO₂ 7.5, O₂ 0.9, H₂ 3.0, N₂ 58.3 per cent. by volume. The first step in combustion control of the stoves was the taking of spot samples of the flue gases with an Orsat set, and adjusting the air valves until the highest CO₂ percentage was obtained and no unburnt gases were present. The average determinations made in this series of tests are shown by means of a graph, and a table gives the settings of the air valves which were adopted. By slight adjustment of the air valves an average of 23 per cent. CO₂, equivalent to 14 per cent. excess air, was easily maintained. A number of heat trials were carried

out, and the calculations based upon the average results obtained are given.

The Flow of Gases in the Blast-Furnace Stove. R. Kahlenberg. (*Stahl und Eisen*, 1928, Vol. 48, Jan. 19, pp. 65-71). In measuring the draught of stoves in the ordinary way, the actual pull and the resistances to flow are measured conjointly. It is not possible to calculate separately the actual pull without knowing the distribution of temperature in the stove itself. A mathematical method is given for calculating separately the pull and the resistance to flow, the measurements having been made on two stoves. Arithmetical analysis of the results shows that losses due to friction occur only in the checkers, and that in all other parts losses are due to baffling. Methods for estimating these losses are given, with suggestions as to the improvement of the efficiency of the plant. The most important consideration is to secure that the gas shall flow as evenly as possible through each passage in the checkers, a condition which is difficult to attain, but may be promoted by allowing ample space in the dome and in the bottom chamber. The pull in these passages is to some extent compensatory: those where the strongest flow takes place heat up sooner than the others, and the resistance to flow is accordingly increased and other passages then take a larger share; but absolute evenness of distribution cannot be expected.

Calculation of Regenerators, and in Particular of Cowper Stoves. J. Seigle. (*Génie Civil*, 1927, Vol. 91, Dec. 10, pp. 577-582; Dec. 17, pp. 609-612). After a brief description of a Cowper stove the three main features of the Pfoser-Strack-Stumm system are enumerated (increased heating surface, better mixing, and more intense circulation of the air-gas mixture). Calculations are made to show that increased efficiency is obtained by the P.S.S. system of regeneration.

The Calculation of Regenerators and particularly of Cowper Stoves. J. Seigle. (*Génie Civil*, 1928, Vol. 92, Jan. 14, pp. 34-37). The author deals here with the case where the heating and heated "calorific mass" have not the same value. He considers, first, the efficiency of the checker-work and the losses due to radiation; he then makes his equations generally applicable by supposing that the coefficient of transmission of heat from the hot gases to the bricks is not the same as that from the bricks to the gases. He also indicates the influence of radiation.

Blast-Furnace Data and their Correlation. E. C. Evans and F. J. Bailey. (Paper read before the Iron and Steel Institute, Annual Meeting, May 1928: this Journal, p. 53).

An Experimental Inquiry into the Interactions of Gases and Ore in the Blast-Furnace. W. A. Bone, L. Reeve, and H. L. Saunders.

(Journal of the West of Scotland Iron and Steel Institute, Session 1927-28, Vol. 35, Part 4, pp. 50-77). This paper was first presented to the Iron and Steel Institute, and is published in Journal No. I., 1927, p. 127.

Calculations of the Carbon required (or of the Quantity of Oxygen Liberated) in Actual Reduction of Iron in the Blast-Furnace. E. Maurer. (Stahl und Eisen, 1928, Vol. 48, Jan. 5, pp. 7-8). A variety of formulæ are to be found in literature for the calculation of the carbon consumed in actual reduction of iron in the blast-furnace, or of the quantity of oxygen (of the burden) liberated. Grüner was the first to work out a formula which became standard; Wedding calculated a simpler one which J. W. Richards has adopted in his book "Metallurgical Calculations"; independently of these, Wüst worked out two general formulæ, and Mathesius, Osann, and Thaler each followed with a new one. Maurer shows that although these different formulæ seldom yield equal results in their application, they are all practically convertible into one another and can be regarded as giving trustworthy results.

Blast-Furnace Investigations. G. Bulle. (Stahl und Eisen, 1928, Vol. 48, Apr. 5, pp. 433-440). The article consists of a summary report of the whole of the results of the investigations on blast-furnace working carried out since 1925 by a Sub-Committee of the Society of German Ironmasters. Four lines of inquiry were pursued: (1) Influence of character of the burden and coke quality on the furnace working; (2) internal reactions in the furnace; (3) influence of blast-furnace lines on production; (4) questions of operation. The reducibility of the ore mixture and degree of reactivity of the coke are purely relative considerations and depend mainly upon the conditions of operation. A coke with low reactivity used with an easily reducible ore mixture will burn just as well as a coke with high reactivity working on a mixture of hard Swedish ore. Trials with minette ores showed that the uniform grading of all materials charged has, in general, a good effect on the furnace working. At one furnace a saving of 20 to 50 kg. of coke per ton of pig was realised, but the dust in the waste gases was increased by 28 per cent. Hand-breaking of the ore gave better results than machine crushing. With a charge consisting of 12 to 27 per cent. of graded sintered fines, the coke consumption was reduced in one case by 200 kg. per ton. One of the difficulties attending grading is that after screening the whole material, say, to 2-in. size, careful tests have shown that about 20 per cent. of both the screened coke and ore may be smaller than $\frac{1}{2}$ in., and a large proportion of these smalls is dust and breeze. A very exhaustive study of the internal reactions was made by analysing some thousands of gas samples taken at different levels and by taking some hundreds of measurements of internal pressure. A special water-cooled tube (illustrated) was used for drawing off the gas samples, and another tube of special design was employed for withdrawing samples

of solid materials at different levels. The data derived from all these operations are tabulated and plotted in diagrams.

Investigation on the Hearth and Bosh of a Blast-Furnace. W. Lennings. (*Archiv für das Eisenhüttenwesen*, 1928, Vol. 1, Mar., pp. 549-564). Trials were made on a blast-furnace with a hearth diameter of 12 ft. 9 in.; about 1100 samples of gas, metal, and slag taken in front of the tuyeres, in the bosh, and in the shaft, were analysed. By injecting water into the blast, useful information was obtained concerning the flow of the gases in front of the tuyeres. The results confirm those of Van Vloten and the Bureau of Mines—namely, that there is an annular zone about 1 m. in depth in front of the tuyeres of a blast-furnace in which the oxygen burns the coke to CO through CO_2 . In consequence of the great evolution of heat in this region, the main part of the iron is melted while passing through this zone, while within the hearth there is a dense incandescent core in which carburisation of the metal and direct reduction of the metallic oxides of the slag take place. These oxides are derived partly from the ore lumps which have remained unreduced, partly from the constituents of the pig iron which are reoxidised in the oxidation zone before the tuyeres. The rate of exothermic combustion of metal before the tuyeres and the endothermic reactions of reducing back in the hearth vary locally and necessitate a larger heat consumption for the reduction of the iron, which must be met either by a higher coke consumption before the tuyeres or by an increase in the blast temperature.

The course of the upward gases and the change in their composition was followed, and the degree of reduction and the coke combustion in the several furnace zones were calculated. It was found that the duties of the hearth and bosh regions are by no means confined to the simple process of smelting, but important metallurgical reactions proceed therein.

The results show that an increase in the hearth diameter by no means reduces the loss of metal by burning in front of the tuyeres. This loss remains comparatively the same whether the hearth is of large or small diameter. Since, however, the area of the combustion zone in front of the tuyeres increases approximately linearly with the hearth diameter, there occurs a linear increase in the hourly effect of the coke combustion which, other conditions being equal, leads to an increased production of the furnace with increase of hearth diameter.

The article recapitulates in much fuller detail some of the results summarised in Bulle's article above.

The excellence of the illustrations and diagrams serves to render the method of investigation and the results exceedingly clear.

Contribution to the Study of the Blast-Furnace Process. G. Eichenberg and P. Oberhoffer. (*Archiv für das Eisenhüttenwesen*, 1928, Vol. 1, Apr., pp. 613-628). The report describes another of the series

of exhaustive experiments performed under the direction of the Blast-Furnace Committee of the Verein Deutscher Eisenhüttenleute. The trials were made on a blast-furnace of the Becker Co., Ltd., at Krefeld, running on foundry iron. In order to get as correct a picture as possible of the conditions within the furnace, arrangements were made for taking a large number of gas samples simultaneously at different levels and distances from the walls, at the same time making measurements of the temperature and pressure conditions. The variation of the gas composition at the same level is ascribed to the presence of an annular zone of combustion, and any alteration in the design of the bell and top appears to have less influence on the distribution of the gases than is supposed. It was found that at 900° to 1000° (at about one-third the height of the shaft) the carbon practically disappears from the gas phase, which would indicate that the charge takes up carbon in this range. At the next two higher levels at which measurements were made, where the temperature was between 1000° and 700° , the carbon reappears in the gas, but this carbon can hardly be derived from direct reduction, and it arises no doubt from the reduction of the carbonates and enters the gas phase in the form of carbon dioxide. A change in the temperature of the blast affects the conditions only in the lower part of the furnace, and at a temperature of 1000° the effect extends to 19 ft. above the tuyere level. The silicon content of the pig rises and falls with the temperature in the bosh. A separate heat balance for the upper and lower parts of the furnace, and heat balances at several different levels, were calculated, and it was concluded that with the kind of burden and with the class of pig smelted, the efficiency of the furnace could not be improved.

A New Theory of the Blast-Furnace Process. F. Wüst. (Stahl und Eisen, 1928, Vol. 48, Apr. 19, pp. 505-506). Notwithstanding that Ebelmen in 1844 and Van Vloten in 1893 have given sound proof of the existence of an oxidation zone in front of each tuyere of a blast-furnace, and that their observations have been fully confirmed by Wüst in 1910 and 1926, this occurrence still lacks general acceptance among blast-furnace experts and theorists. The author enumerates a set of theses which, though likely to be strongly opposed, he is prepared to prove point by point; the main theses are as follows:

In front of each tuyere of a blast-furnace there exists a zone of oxidation, which exercises a disadvantageous effect on the working of the furnace.

The diminishing of this oxidation by any suitable means will improve the production, as, for instance, the use of charcoal instead of coke, heating the blast, use of dry blast, injection of liquid fuel, or increasing the hearth diameter.

The reoxidation before the tuyeres leads to the taking up of a large if not excessive proportion of the foreign constituents above the tuyere level.

The splitting of the carbon monoxide according to the equation $2\text{CO} = \text{C} + \text{CO}_2$ favours the reduction in the furnace, and this splitting up is strongly promoted by heating the blast.

The scaffolding of the charge is influenced not only by the porosity of the ores, but by the top temperature.

The so-called direct reduction of the iron, silicon, and phosphorus takes place chiefly above the tuyere level, being brought about mainly by the carbon monoxide.

The greater part of the foreign constituents of the pig iron are taken up by cementation of the iron in the shaft or bosh. In the hearth, in smelting ordinary pig irons, only a comparatively small proportion of foreign constituents is taken up by direct reduction from the slag.

The degree of reduction of the ores cannot be judged by taking gas samples for analysis at any level of the furnace, and the working of the furnace cannot be judged by estimating the ratio of carbon dioxide to carbon monoxide.

Hydrogen probably plays a great part in the indirect reduction of the ores, the water formed being again reduced to hydrogen by reaction with the carbon monoxide.

Cyanide and its Compounds in the Blast-Furnace. W. Haufe and H. von Schwarze. (*Archiv für das Eisenhüttenwesen*, 1928, Vol. 1, Jan., pp. 453-466). A summary of the literature on the formation of cyanide compounds in the blast-furnace is given, beginning with Bunsen and Playfair's experiments of 1845, and the work of investigators down to the present day is reviewed. As the result of inquiries addressed to a number of blast-furnace managers, it is shown that pure cyanide is never formed, though small quantities of prussic acid may form, but they are not stable. It is generally assumed that the formation of cyanide of potassium takes place through the carbide and cyanamide, and all other cyanide compounds found in the blast-furnace dust, including prussic acid, are products of secondary reactions with cyanide of potassium, except cyanide-nitro-titanate, which is formed when titanium, nitrogen, and carbon come in contact with each other.

The formation of cyanide salts is very injurious, and the small advantage gained from the use of cyanide as a reducing agent and indirectly as a desulphuriser is far exceeded by the disadvantages of its accumulation, which are manifest chiefly in the eating away of brickwork, wear of tap holes, and higher coke consumption. Cyanide compounds in the blast-furnace dust can also be the cause of trouble. However, the recovery of cyanide of potassium may be profitable, as Kinney and Gurney have shown in their report of 1926 (U.S. Bureau of Mines, Technical Paper No. 390, pp. 37). By drawing off 10 per cent. of the gas at the bosh of a 300-ton furnace a daily profit of 104 dollars was possible with cyanide of potassium at 22 cents a kilo,

the cost of the recovery plant being quite moderate. By increasing the amount of gas drawn off to 20 per cent. the profit rose to 197 dollars daily.

On the Influence of Temperature in the Blast-Furnace on the Carbon Content of Grey Pig Iron. A. Michel. (Giesserei-Zeitung, 1927, Vol. 24, Oct. 15, pp. 567-569).

Investigations of the Equilibrium Conditions of the Reduction, Oxidation, and Carburisation Processes in Iron. R. Schenck. (Zeitschrift für anorganische Chemie, 1927, Vol. 164, pp. 145-185, 313-325; Vol. 166, pp. 113-154; Vol. 167, pp. 254-314, 315-328; Stahl und Eisen, 1928, Vol. 48, Jan. 5, pp. 15-21). The author reports the results of a series of exhaustive investigations on the equilibrium conditions of oxidation, reduction, and cementation processes. The chief object of the research was to explain the behaviour of carbon monoxide, carbon, and iron carbide in relation to the iron oxides and the pure iron itself.

Equilibria in the Reduction of Ferric Oxide. C. C. Furnas and G. G. Brown. (Industrial and Engineering Chemistry, 1928, Vol. 20, May, pp. 507-510). The authors have used new thermal data on ferric oxide with data already published, and compute, by means of the third law of thermodynamics, the equilibrium constants of reactions involved in the reduction of ferric oxide. The results are compared with experimental results obtained by other investigators.

Desulphurising in the Blast-Furnace. C. H. Herty, jun., and J. M. Gaines, jun. (Blast-Furnace and Steel Plant, 1928, Vol. 16, Feb., pp. 233-237). The authors have been attempting to formulate a theory to explain, from a physico-chemical viewpoint, the various phenomena occurring in the lower part of the blast-furnace. Attention thus far has been directed almost entirely to the question of sulphur, and the theory relating to it is presented together with other data in its support. The findings of Kinney, Goldberg, and Michel are summarised. The probable reactions during desulphurisation are explained. ✕

Smelting in the Blast-Furnace of Zinc-Bearing Ores, in Particular the Meggen (Westfalia) Pyrites Residues. M. Paschke. (Archiv für das Eisenhüttenwesen, 1927, Vol. 1, No. 6, Dec., pp. 387-402). Large-scale experiments were made in a blast-furnace to discover whether it is possible to utilise the pyrites residues of which about 200,000 tons become available at Meggen every year. They contain some 43 per cent. iron, 6 to 10 per cent. zinc, and 4 to 8 per cent. sulphur. Two methods of sintering the residues were tried, one using a rotary roasting furnace, the other a Dwight-Lloyd sintering bed. The product of

the former method was more satisfactory when briquetted, and the Dwight-Lloyd product was better without briquetting. The sinter briquettes contained iron 36, zinc oxide 6.77, and sulphur 0.53 per cent. In the furnace trials, the sinter was added in the proportion of 25, increasing to 50 per cent. by weight, to 75 and 50 per cent. respectively of the other iron-bearing materials (ore, mill scale, scrap). Common salt up to 2.15 per cent. by weight was then added. Beyond about 40 per cent. of sinter briquettes the furnace showed signs of giving trouble. The furnace, it should be said, was running on high manganese pig (*Stahleisen*) with Mn = 4.19 per cent. The weight of ZnO in the burden per 100 kg. of iron produced was 5.87 kg., of which 0.43 kg. was carried off as dust, the remaining 5.44 kg. being volatilised by the chlorides to zinc chloride and oxychloride and deposited as sludge. No zinc deposits whatever remained in the furnace or gas mains, nor could a trace of zinc be found in the resulting pig. The subsequent maximum recovery of zinc from the sludge was 82.4 per cent. of the total charged. The sulphur driven off in the sintering process can be utilised for the zinc recovery. The trials showed that out of 200,000 tons of pyrites residues, smelted with common salt in the blast-furnace, a yearly yield might be expected of 80,000 tons of iron, 14,000 tons of zinc, and 8000 tons of sulphur.

Production of High-Alumina Slags in the Blast-Furnace. T. L. Joseph, S. P. Kinney, and C. E. Wood. (American Institute of Mining and Metallurgical Engineers, 1928, Technical Publication No. 112). In the absence of any experimental evidence that a blast-furnace could be operated on a burden of iron ore, bauxite, limestone, and scrap, melting-point determinations were an invaluable guide in predicting the behaviour of high-alumina slags. Melting-point determinations indicate that it would be feasible to operate a furnace on slags containing 47 to 48 per cent. Al_2O_3 , 41 to 42 per cent. CaO , 4 to 5 per cent. SiO_2 , and small percentages of TiO_2 , MgO , and S. In general, slags containing CaO and Al_2O_3 in about equal amounts will have the lowest melting points when the percentage of CaO exceeds the percentage of Al_2O_3 .

Viscosity determinations in the ternary system $\text{CaO-Al}_2\text{O}_3\text{-SiO}_2$ show that the ternary eutectic, composed of 49.5 per cent. CaO , 43.7 per cent. Al_2O_3 , and 6.8 per cent. SiO_2 , has relatively low viscosity, and that only a small change in viscosity takes place with changes in temperature above the melting point.

Although there was evidence that a blast-furnace could be operated on slags containing about equal percentages of lime and alumina with 6 to 10 per cent. silica, some sort of a practical demonstration was needed to obtain positive information. It was desirable furthermore to obtain a substantial quantity of slag to determine the relative ease of extracting alumina from high-alumina slag as compared with ex-

tracting alumina from crude bauxite. Operating data from the experimental furnace were also needed to determine the economic possibilities of treating high-iron bauxite in the blast-furnace to produce a calcium aluminate slag for the manufacture of aluminium.

During a two-week test, experimental furnace slags were produced covering a range of composition as follows: 6 to 33 per cent. SiO_2 , 35 to 52 per cent. CaO , 18 to 53 per cent. Al_2O_3 , about 2 per cent. TiO_2 , about 1 per cent. FeO , and 0.5 per cent. S. There was no difficulty in operating the furnace on slag varying over this wide range of composition. The temperature-viscosity relations of slag do not change directly with gradual changes of a single constituent. Although alumina increases viscosity in some ranges of composition, in others it decreases viscosity. Metal low in sulphur was produced due to the temperature of the slag, to its large volume, and primarily to the availability of the lime for reacting with iron sulphide.

High-alumina slags lose their strong desulphurising power at lower temperatures. Preliminary laboratory tests show that calcium aluminates desulphurise metal rapidly at 1500° to 1525°C . Although there is experimental evidence to show that CaS is more soluble in slags containing higher percentages of alumina, the marked capacity of such slags to desulphurise metal is attributed largely to the basicity of the slag or the amount of lime which is available to act as a driving force in the formation of CaS .

Silica was oxidised from the borings charged because the blast had an oxidising effect in the combustion zone and, moreover, unreduced iron oxides reached the hearth. The marked oxidation of silicon from scrap charged in the experimental furnace would be much less pronounced in full-size furnaces.

Modern Scientific Principles in the Working of Blast-Furnaces of Large Output. M. Derclaye. (*Revue de Métallurgie, Mémoires*, 1928, Vol. 25, Jan., pp. 1-13; Mar., pp. 120-147). The aim of the paper is to prove that a blast-furnace may be both "productive" and economical, and the influence of the factors dependent either on the fuel, or on the furnace itself, or on the physical state of the materials within the fusion zone, on the production or on the economy of fuel, is pointed out. The whole matter is dealt with theoretically.

Choosing Scrap for the Blast-Furnace. D. M. McLain. (*Canadian Foundryman*, 1927, Vol. 18, Sept., pp. 13-14). According to the author, plain carbon steel scrap is to be preferred to grey iron scrap on account of its low phosphorus content, and its ability to produce stronger pig iron.

Pig Iron Quality is affected by Scrap Additions to Blast-Furnace. J. L. Jones. (Paper read before the French Foundry Technical Association: *Foundry*, 1928, Vol. 56, Jan. 1, pp. 32-34). The presence of

undesirable alloys is one of the chief difficulties met with in the use of scrap in the blast-furnace burden. Trouble is also caused by the use of oxidised scrap, and lack of uniformity due to the irregular mixing of the steel in the burden.

Blast-Furnace Practice in Natal. J. E. Holgate and R. R. F. Walton. (Paper read before the Iron and Steel Institute, Annual Meeting, May 1928: this Journal, p. 209).

The Manufacture of Pig Iron in Natal. J. E. Holgate. (Paper read before the Chemical, Metallurgical, and Mining Society of South Africa: Iron and Coal Trades Review, 1928, Vol. 116, Mar. 30, pp. 461-462).

Fuel Economy on Blast-Furnace Plants. J. B. Fortune. (Fuel Economist, 1928, Vol. 3, Apr., pp. 445-450). The commencement of a series of articles dealing with some of the aspects of the fuel problem as related to blast-furnaces and their auxiliary equipment. The present article discusses automatic blast regulation, drying of blast, utilisation of surplus gas, and hot-blast stove efficiencies.

Operation of Blast-Furnace Plant of Columbia Steel Corporation at Ironton, Utah. W. R. Phibbs. (American Institute of Mining and Metallurgical Engineers, 1928, Technical Publication No. 109). The results show that the sizing of the ore and the uniform small coke have an important bearing on the operation of the furnace. Tests have shown that 3 ft. under the stock line the velocity, temperature, and analysis of the gas are uniform across the plane of the furnace. The CO₂ content is exceptionally high. This condition is due to the uniform distribution of the sized ore and small coke. Part of the product is basic iron, the balance is various grades of foundry iron, mostly high-silicon foundry, and these grades require different percentages of manganese and phosphorus, which are controlled in the burden by using high-manganese ore and phosphate rock. Due to making the various grades of iron, it is impossible to have a long run on any one particular grade of iron. In the past few months, periods have averaged 441 tons of basic iron per day on coke consumption of 1685 lb. of coke per ton of iron. On foundry iron there were periods averaging 400 tons per day with coke consumption of 1878 lb. of coke per ton of iron. The average flue-dust per ton of iron produced since the beginning of operation is approximately 50 lb., and the maximum wind blown on this furnace to date has been 33,000 cu. ft. per minute.

A Year's Operation of Betty Furnace. J. H. Slater. (Frey Design, 1928, Apr., No. 5, pp. 1-4). The operating results obtained at the new blast-furnace of the Central Alloy Steel Corporation, Massillon, are presented. This furnace, with a hearth diameter of 18 ft. 6 in., was

blown in on October 28, 1926. The results, averaged for the last six months, are as follows :

Average daily production	725 tons
Ore per ton of iron	3,372 lb.
Scrap per ton of iron	396 „
Sinter per ton of iron	405 „
Limestone per ton of iron	867 „
Gross coke per ton of iron	1,752 „
Net coke per ton of iron	1,734 „
Flue-dust produced per ton of iron	415 „
Cu. ft. of wind per minute	45,000
Actual yield of mixture	52.01 per cent.

Approximately 1050 lb. of slag are produced per ton of iron. There are four stoves each with a heating surface of 81,300 sq. ft. Blast temperature is usually about 1200° F., but when desired a temperature of 1700° F. is easily reached. Gas enters the washer at about 300° F. and leaves at 69° F., passing through a heat exchanger, where the temperature is raised to about 104° F. by waste gases from the stoves.

Blast-Furnace Practice in Germany. F. H. Willcox. (Iron Age, 1928, Vol. 121, Mar. 22, pp. 803, 842). Outstanding features in German blast-furnace practice are discussed. In the Ruhr district ore is obtained from Newfoundland, Sweden, Spain, Africa, France, and Luxemburg. The burdens used at various plants are of the most composite character. In one case, that of a three-furnace plant where each stack is of 17,000 cu. ft. capacity and produces 1500 to 1800 tons per day, 32 different iron-bearing materials are used. The low-grade native ore is not much used, and it has been found cheaper to import ores than to develop the low-grade deposits.

Blast-Furnace Operation Abroad. F. H. Willcox. (Paper read before the Eastern States Blast-Furnace and Coke Corporation : Blast-Furnace and Steel Plant, 1928, Vol. 16, Apr., pp. 492-494, 497 ; Iron Trade Review, 1928, Vol. 82, Apr. 5, pp. 872-874). A discussion of blast-furnace practice in Germany.

Blast-Furnace Practice in Germany. H. A. Brassert. (Blast-Furnace and Steel Plant, 1928, Vol. 16, Jan., pp. 8-11). One interesting development that has taken place since the war in Germany has been the large increase in the production of blast-furnaces. At a number of plants the capacity per furnace has been increased 50 per cent., and at some as much as 100 per cent., compared with pre-war practice. This has been largely brought about through the use of richer ores imported from abroad. With regard to furnace design, American practice has been followed in some cases by the introduction of larger hearths and lower, steeper boshes. The latest practice in Germany is to use sinter, which is made principally from ore ; the flue-dust is mostly briquetted.

The sinter is used in percentages varying from 20 to 40 per cent., although as much as 60 per cent. is used in some plants. Blowing equipment in Germany consists mostly of gas engines, generally of the single tandem type, but a few turbo-blowers have been installed recently. Fine ores are generally sintered without any classification by screening, retention of a percentage of coarser ore being preferred as it facilitates the sintering process, and many ores are sintered which are of a coarse nature. In most cases the ores are mixed with mill scale, pyrites, flue-dust, and other cheap materials.

Foundry Pig Iron. R. Fowler. (Foundry Trade Journal, 1928, Vol. 38, Mar. 1, pp. 153-155). The author gives a brief résumé of the difficulties encountered in the manufacture of foundry pig iron, which cause variations in the physical and chemical composition of the final product.

Blast-Furnace Developments in 1927. H. A. Berg. (Blast-Furnace and Steel Plant, 1928, Vol. 16, Jan., pp. 15-17). The author reviews briefly the advances made in American blast-furnace practice during 1927.

The Silica Gel Blast-Drying Plant at Wishaw. (Engineering, 1927, Vol. 124, Dec. 30, pp. 836-837). A brief illustrated description of the blast-drying plant installed at the works of the Glasgow Iron and Steel Co., Ltd., which formed the subject of E. H. Lewis' paper in Journ. I. and S.I., 1927, No. II. pp. 43-55.

The Use of Silica Gel for Drying the Blast for Blast-Furnaces. A. Bidault des Chaumes. (Génie Civil, 1927, Vol. 91, Dec. 31, pp. 661-664). The Wishaw blast-drying plant of the Glasgow Iron and Steel Co., Ltd., is described.

Utilisation Problems of Metallurgical Limestone and Dolomite. O. Bowles. (American Institute of Mining and Metallurgical Engineers, 1928, Technical Publication No. 62). The author deals with blast-furnace fluxes, and discusses the action of flux in the furnace, effect of impurities on fluxing stone; he devises a formula for calculating the relative values of fluxes of different grades. The slagging effect of magnesia, its function as a sulphur remover, and its effect on slag viscosity and slag utilisation, are dealt with. Factors governing the use of impure fluxing stone and the size of stone for blast-furnace flux are also considered. The author also discusses basic open-hearth flux, and concludes with an analysis of the problems in the use of dolomite as a furnace lining.

Concerning the Granulation of Slags. B. Bogitsch. (Revue de Métallurgie, Mémoires, 1927, Vol. 24, Nov., p. 695). In a former

article (*see* Journ. I. and S.I., 1926, No. II. p. 551) the use of a compressed air jet to prevent explosions during the granulation of slags and metals was described. The author here gives further details of precautions to be taken in carrying out the process.

Specifications for the Manufacture and Supply of Blast-Furnace Slag for Road Construction. (Stahl und Eisen, 1928, Vol. 48, May 3, pp. 588-590). A committee appointed to consider the extension of the use of blast-furnace slag has drawn up a set of rules specifying the qualities and sizes of broken slag for construction and maintenance of roads. The rules came into effect in 1927 and are subject to reconsideration at the end of 1932.

Blast-Furnace Slag Bricks. (Iron and Steel Industry, 1928, Vol. 1, Mar., pp. 189-190). Brief particulars are given of the application of the calcium silicate process for the manufacture of blast-furnace slag bricks. The slag in a fine state of division is mixed with 6 to 10 per cent. of slaked lime and a certain amount of water, and is compressed into shape, afterwards being exposed to the direct action of steam at atmospheric pressure. The lime combines with the free silica or the unsaturated silicates present and forms an intensely hard brick.

(Production of) Slag Bricks and Slag Pavement Slabs in Germany. A. Guttman. (Archiv für das Eisenhüttenwesen, 1927, Vol. 1, Nov. pp. 339-344; Stahl und Eisen, 1928, Vol. 48, Jan. 12, p. 39). Five different methods for the production of slag bricks are in operation to-day in Germany and the annual output is about 150 million slag bricks from some twenty works. Most of these works still use Lürmann's method, which is the oldest, and consists of the air-hardening, for several weeks, of a slag-sand-lime mortar. Michaelis introduced steam drying some twenty years ago, and Dresler adopted drying by waste gas, which yielded finished bricks in 40 to 50 hrs. The Scholsche process of 1914 makes light bricks of porous slag dried in air, and the Schönhofer process uses slag meal and slag sand mixed in a pug mill with subsequent air-drying of the mass. Particulars are given in the original article of the properties of these bricks as regards their frost-proof and fireproof qualities, their heat conductivity, absorption of moisture and bonding capacity.

DIRECT PROCESSES.

Notes on a Study of Oxides of Iron, in Particular, Ferrous Oxides. H. Groebler and P. Oberhoffer. (Stahl und Eisen, 1927, Vol. 47, Nov. 24, pp. 1984-1988). Tests were made on the reduction of iron oxide in a mixed current of carbon monoxide and carbon dioxide with the object of obtaining ferrous oxide in as pure a condition as possible

by direct reduction. FeO of 99 per cent. purity can be obtained, using small quantities of ore of about 1 grm. When taking larger quantities, up to 6 grm. in weight and over, FeO of 95 per cent. purity is the best degree obtainable.

A Résumé of the Factors Influencing the Rate of the Gaseous Reduction of Metallic Oxide. P. H. Emmett. (Transactions of the American Electrochemical Society, 1927, Vol. 51, pp. 207-215). It is found that the reducibility of an oxide by a reducing gas depends upon—(1) The chemical nature of the oxide being reduced ; (2) whether the reduction is autocatalytic ; (3) the temperature and method of preparation of the oxide ; (4) whether the oxide being reduced is in mass, or supported in thin layers on a suitable supporting substance ; and (5) whether or not there are present materials intended to promote or increase the activity of the metallic catalyst resulting from the reduction.

ELECTROLYTIC IRON.

Electrolytic Iron. (Foundry Trade Journal, 1928, Vol. 38, Feb. 16, p. 118). Brief notes are given on the manufacture, properties, and uses of electrolytic iron.

Electrolytic Iron : Its Inception and Development. (Engineering, 1928, Vol. 125, Mar. 23, pp. 339-340). A brief history of the science and art of the production of iron by electrolysis.

IRON INDUSTRIES.

Survey of Metal Industries. (London, 1928 : H.M. Stationery Office, Price 5s.). This work forms Part IV. of a Survey of Industries prepared by the Committee on Industry and Trade. It deals in considerable detail with the iron and steel industries and engineering. The first section of the report is mainly historical in character. The second section discusses post-war developments, dealing with productive capacity and methods, organisation of the industry, and economic conditions. A comparison is also made of the British iron and steel industry with foreign plant and practice. The Committee report that a great advance has taken place since 1913 in productive efficiency.

The increase in efficiency of the blast-furnace has on the whole been decidedly less than at the steelworks. In the main, efforts have been directed to improving the auxiliary machinery rather than the furnaces themselves. Thus mechanical charging gear has now been

introduced at about one-quarter of the blast-furnaces. On the Continent its use is more widespread, but it is claimed by the British manufacturers that in some conditions hand-charging is more efficient. A number of new blast-furnaces of large capacity have been built, but there are still many small furnaces in existence with a capacity far below that which is found most efficient from the point of view of quantity of output in modern practice, though in quality of output they may perhaps excel.

Steel-making furnaces of small capacity have been extensively scrapped since 1913 and replaced by furnaces of larger capacity. While the number of furnaces of a capacity of less than 50 tons has fallen from 394 to 283, the number of a capacity of 50 tons or more has risen from 152 to 349.

In the efficiency of its coking plant and in the organisation of the coking industry, Great Britain still undoubtedly lags behind the United States and the Continent of Europe.

The British overseas trade in iron and steel manufactures is dealt with in the third section of the Report, while the fourth and concluding section is devoted to the British iron and steel industries in relation to world production and trade.

Iron and Coal Trades Review—Diamond Jubilee Issue, 1867–1927. This special number contains contributions by well-known authorities describing progress in the coal and iron and steel industries during the past sixty years in this country and abroad. The British iron and steel industry is dealt with in the following articles: The Iron and Steel Age, by Sir W. J. Larke; Sixty Years of Iron Ore Mining, by H. K. Scott; The Iron Trade of Great Britain and the World, by Sir Hugh Bell, Bt.; Blast Furnace Design, 1867–1927, by D. E. Roberts; Review of Blast-Furnace Practice, 1867–1927, by A. K. Reese; Iron and Steel Economics and Costs, with Special Reference to the Subject of Protection, by Sir F. Mills, Bt.; Sixty Years of Steel Manufacture and Steelworks Design, by W. Simons; Development of Open-Hearth Steel Practice during the last Sixty Years, by T. Baker; The Development of the Rolling-Mill with the Advent of Steel, by J. W. Hall; The Tinsplate Trade from a Commerical Standpoint, by Sir Edgar R. Jones; The Tinsplate Industry: Sixty Years of Technical Development, by H. Spence Thomas; Sixty Years of Wrought Iron Industry, 1867–1927, by J. S. Trinham; Sixty Years Progress in the Metallurgy of Iron and Steel, by Sir R. Hadfield, Bt.; Sixty Years of Labour Progress in the Iron and Steel Industry, by A. Pugh; Iron and Steel Home and Export Trade, by H. J. Skelton; Sixty Years of Foundry Practice, by V. C. Faulkner. The iron and steel industries of the leading foreign countries are dealt with in the following articles: The American Iron and Steel Industry, by B. E. V. Luty; The German Iron and Steel Industry during the past Sixty Years, by E. Buchmann; Development of the French Iron and Steel Industry, by Lambert-Ribot; 1928—i.

The Belgian Iron and Steel Industry during the Past Sixty Years, by J. Van Hoegaerden. The functions and activities of the Associations and Institutions connected with the iron and steel industry of the United Kingdom are dealt with by various contributors.

The Iron and Steel Industries of the West of Scotland. T. B. Mackenzie. (Iron and Steel Industry, 1928, Vol. 1, Jan., pp. 121-126). A general illustrated description of the iron and steel works in the west of Scotland district.

Cost in the Coal, Iron, and Steel Industries. (Iron and Coal Trades Review, 1928, Vol. 116, Apr. 6, pp. 495-496; Apr. 13, pp. 521-524; Apr. 20, pp. 565-566; Apr. 27, pp. 598-599). The Committee on Industry and Trade have published the fourth instalment of their report entitled "Further Factors in Industrial and Commercial Efficiency." Considerable space is devoted to costs of production in various industries, and those relating to the coal, iron, and steel industries are given.

Iron Smelting and Steel Making in Canada. F. W. Gray. (Iron and Steel of Canada, 1928, Vol. 11, Jan., pp. 4-6). The present economic condition of the Canadian iron and steel industry is reviewed and compared with that of 1913.

Industrial Development in South Africa. (The Department of Mines and Industries, Pretoria, 1927). The object of the Report is to give an up-to-date review of the possibilities of the Union of South Africa as an industrial country, and includes particulars of the iron ore resources and iron smelting establishments.

Economic and Financial Conditions in Germany, July 1927. J. W. F. Thelwall and C. J. Kavanagh. (Dept. of Overseas Trade, London, 1927: H.M. Stationery Office). This report contains a section by C. J. Kavanagh dealing with the German metallurgical and engineering industries, in which the industrial policy of the country is reviewed. The reorganisation of the iron and steel industry is also dealt with.

The Position of the Siegerland, During and After the State Subsidy. (Stahl und Eisen, 1928, Vol. 48, May, 10, pp. 609-615). The Siegerland is one of the oldest iron-working districts in Europe, the history of which goes back to legendary times, and the oldest written record dates back to about the year 1200. The normal output of the manganiferous ore for which the district is famous is $2\frac{1}{2}$ million tons annually, and for the German iron industry these resources are a most important economic factor. A map of the district is given showing the numerous workings. In the nineteenth century as many as 300 iron mines were in operation, but in the years before the war the number had come

down to 60. At the present day only 30 mines remain in operation, of which 6 or 7 furnish 50 per cent. of the total output. The raw ore has up to 28 to 30 per cent. iron, with 4 to 6 per cent. manganese, but contains besides sulphur and copper pyrites, zinc blende, galena, silica, and alumina. Roasting is therefore indispensable, which considerably increases the cost of the product. The roasted ore contains 47 to 50 per cent. iron and 8 to 11 per cent. manganese. The ore is mined through shafts, the deepest of which, at Gosenbach, is about 3300 ft. The resources still available are : ore in sight 7,700,000 tons, and known reserves to a depth of about 4300 ft. 54,000,000 tons, or a total of about 61,700,000 tons. The disorganisation of industry in the years following the war led to great depression, and in 1926 only 11 mines were still working ; employment had fallen from 12,000 to 5000 men, and the monthly output was down to 70,000 tons. The authorities represented to the Government that unless reductions were made in social contributions, taxes, freights, and electric current charges, the whole industry must come to a standstill. As none of these demands could be promptly met, the Government agreed as an emergency measure to grant a subsidy of 2 marks on every ton of ore raised and exported from the district, subject to a proportionate reduction in the selling price. This arrangement came into force in June 1926, and the relief exceeded expectation, for by March 1927 the output had reached 200,000 tons a month, and the total output for 1927 was very nearly the normal of $2\frac{1}{2}$ million tons. In September 1927 the subsidy was withdrawn and slight reductions in railway freights and readjustments in taxation have made it possible for the mining industry to carry on, though the economic position is still regarded as precarious.

Less New Capacity in 1927. (Iron Age, 1928, Vol. 121, Jan. 5, pp. 78-83). Particulars are given of the additions made to the blast-furnace and open-hearth capacities of the American iron and steel industry during the year 1927.

Metallurgical Developments of 1927. S. Goodale. (Blast-Furnace and Steel Plant, 1928, Vol. 16, Jan., pp. 46-48). Important new advances made during the year in blast-furnace and foundry practice, in steel plant equipment and operation, and in rolling-mill design are reviewed.

Increasing Blast-Furnace Capacity. (Iron Age, 1928, Vol. 121, Feb. 9, pp. 415-416). Particulars are given showing the number and capacity of blast-furnaces erected and in blast in the United States during the period 1891-1927. The number of blast-furnaces has decreased 34 per cent. in the past 37 years, but the capacity has quadrupled. In 1891 there were 573 furnaces in existence with a capacity of 13 million gross tons ; at the end of 1927 there were 379 furnaces, with a capacity of more than 51 million tons.

Japan, a Growing Producer of Steel. G. S. Herrick. (*Iron Age*, 1928, Vol. 121, Jan. 5, pp. 55-59). A review is given of the Japanese iron and steel industry. The blast-furnace, open-hearth, and rolling-mill capacities of the different works are tabulated. A list is also given of the works showing the number of furnaces and the class of material produced.

HISTORICAL.

A Vanished Industry. J. H. Every. (Lecture to the Institute of British Foundrymen, Feb. 2; *Foundry Trade Journal*, 1928, Vol. 38, Feb. 16, pp. 109-110). A brief discussion of outstanding features of the ancient Sussex iron industry.

The Making and Rolling of Iron. J. W. Hall. (Paper read before the Newcomen Society, Dec. 7, 1927; *Engineer*, 1927, Vol. 144, Dec. 16, p. 689). The author relates the history of the development of the making of wrought iron from the earliest "finery" process up to Hall's "pig-boiling" process, and describes the origin and development of methods of rolling metals.

The Ancient Iron Industry in the Salm Valley. A. Faber. (*Revue Technique Luxembourgeoise*, 1927, Vol. 19, Nov. and Dec., pp. 159-166).

The First Ironworks in America, 1645. H. Corning. (Paper read before the American Iron and Steel Institute, May 25, 1928). An interesting account is given from old records of the events leading up to the erection and operation of the first ironworks built in America, near Boston, Massachusetts, in 1645. The site of the works was for some time known as Hammersmith, after the place in England, from which the first skilled workers were obtained. Other workers were secured from a batch of Scottish prisoners captured by Cromwell at the battles of Worcester and Dunbar. These were obtained at a cost of £5 each in England, and were sold for ten years' service in America for £20 each. The undertaking, which was financed by merchants in London, ceased to exist in 1688.

FOUNDRY PRACTICE.

GENERAL FOUNDRY PRACTICE.

The Control of Cupolas. H. Carra and R. Fric. (*Chaleur et Industrie*, 1927, Vol. 8, Dec., pp. 673-678 ; 1928, Vol. 9, Jan., pp. 19-30). The authors discuss the control of cupolas with a view to obtaining the utmost economy of fuel without, however, reducing the temperature and quality of the tapped metal to a point where it would be unsuitable for the foundry. A chart from a combined air pressure recorder and air meter is reproduced to show that when the blower is manipulated the curves rise or fall together, whereas when anything occurs in the cupola the curves move in opposite directions, thus indicating where to look for the trouble. The use of gas analysis to control the working of cupolas is also discussed.

The Cupola Furnace. J. E. Hurst. (*Iron and Steel Industry*, 1928, Vol. 1, Feb., pp. 147-150 ; Mar., pp. 177-180 ; Apr., pp. 219-221). The author deals with first principles and, after conceding the heat inefficiency of the cupola, discusses the reactions and theories involved in cupola practice. He next deals in detail with the heat balance and the proper method of stating it. Details of cupola practice, such as the melting zone, the height of the bed of coke, normal melting rate, quantity, velocity and pressure of air supply, CO_2/CO ratios, and the relation of air to coke ratios, are discussed.

The History of the Foundry Cupola. J. E. Hurst. (*Engineering*, 1927, Vol. 124, Dec. 30, pp. 830-831).

Cupola Construction. R. Thews. (*Giesserei-Zeitung*, 1927, Vol. 24, Dec. 15, pp. 686-688). The author discusses various points which need consideration when building a cupola, such as the relationship between the internal diameter and the throughput, the height of the furnace, the number, size, and arrangement of the tuyeres, the dimensions of the pipes conveying the air-blast, and of the wind-box. Practical hints are given.

The Ruscoe Cupola Charger. (*Foundry Trade Journal*, 1927, Vol. 37, Nov. 17, p. 117). Brief particulars are given of the Ruscoe automatic cupola charging machine, which can be attached to existing plants and renders installation of a hoist unnecessary.

Automatic Charging of Cupolas. H. A. Jahraus. (Iron Age, 1927, Vol. 120, Nov. 17, pp. 1363-1366). A detailed illustrated description is given of the automatic charging equipment at the foundry of the Buick Motor Co.

Charging Coke by Machinery. F. L. Prentiss. (Iron Age, 1927, Vol. 120, Nov. 17, pp. 1372-1373). A description is given of the method of mechanically making up the charges of pig iron and scrap, the method of charging the cupolas, and the new automatic conveying and charging equipment for delivering coke and limestone to the cupolas at the plant of the Buick Motor Co.

Cutting Costs and Avoiding Accidents. G. F. Tegan. (Iron Age, 1928, Vol. 121, Feb. 16, pp. 461-462). The author describes a mechanical charging system for cupolas in operation at the plant of the Union Switch and Signal Co., Swissvale, Pa. The storage bins are built below ground-level, over which runs a trestle. There are nine bins—five for pig iron and one for scrap on one side of the scale car pit, and two for coke and one for limestone on the other. The bin house is 90 ft. long and 45 ft. 3 in. wide, and is 21 ft. deep at the level of the scale car pit, which is approximately 6 ft. below the bottom of the bin floors. Steel buckets are used for charging, capable of holding 4000 lb. of pig and scrap, 400 lb. of coke, and 65 lb. of limestone. When a charge is made up the scale car moves to an opening at the end of the bin house. Here the bucket is lifted by a 3-ton hoist and conveyed by monorail to the cupola. To permit entry of the large charging bucket, the cupola has been cut away at the charging door. It is stated that the system has saved 66 per cent. in operating charges.

Savings from Hot-Blast Cupola. F. K. Vial. (Iron Age, 1927, Vol. 120, Oct. 27, pp. 1155-1156). The author presents a comparison of hot- and cold-blast cupola practice. Under ordinary conditions the hot-blast cupola requires 20 per cent. less air than is required in ordinary cupolas. The blast-pressure required is about one-half of that usual in ordinary practice.

On the Question of the Carburisation of Steel Scrap in the Cupola. P. Lorinser. (Die Giesserei, 1928, Vol. 15, Apr. 20, p. 366). As a result of a large number of experiments briefly described in the article, the author is of the opinion that the carburisation of steel in the cupola varies widely both from furnace to furnace, and even in any one cupola furnace. A certain relationship between the temperature of the iron and its carbon content was noted; the higher the melting temperature of the furnace, the smaller was the amount of carbon taken up, a point which should be of some use in processes for the production of high-duty cast irons.

Cupola Melting, with Special Reference to the Value of Steel Scrap in Cupola Mixtures. W. Dennison. (Foundry Trade Journal, 1927, Vol. 37, Dec. 29, pp. 225-226). The author claims that the use of steel scrap in a cupola mixture has a beneficial influence on the physical properties of the resultant metal even when the chemical composition gives no indication of such improvement. The percentage of steel used to obtain the best results will vary from 5 per cent. for the lightest of castings to 40 per cent. for the heaviest.

Steel Scrap Additions Make High Test Cast Iron. A. J. Meissner (Foundry, 1928, Vol. 56, Mar. 15, pp. 229-230). The author presents the results of tests on the use of steel scrap in the cupola for the production of high-grade cast iron.

The Manufacture of Steel-Mix Grey Cast Irons, with Special Reference to their Treatment in the Foundry. A. Smith. (Foundry Trade Journal, 1928, Vol. 38, Feb. 2, pp. 77-79). The author discusses in some detail the production of semi-steel cast iron, giving particulars of cupola design, charging practice, and mixtures used. By the adoption of suitable mixtures and correct melting technique, it is possible to make with perfect regularity 30 to 60 per cent. steel-mix grey cast irons, which will be almost entirely pearlitic in structure, be readily machinable, and yet possess vastly superior properties to grey irons made from pig iron alone or pig iron mixed with cast-iron scrap. Steel-mix irons may be roughly divided into two distinct classes—namely, (1) with total carbon 2.8 per cent. or less to 3.2 per cent., and (2) with total carbon over 3.2 per cent., and, in the author's opinion, the term high-duty steel-mix grey cast iron can only be applied to the first class containing moderately low carbon. Details are given of the composition and physical properties of numerous representative casts of steel-mix grey iron, the percentage of steel scrap used being stated in each case. In addition a few examples are given where nickel has been added with the idea of maintaining the strength of the iron and at the same time improving the machinability. A table is also included showing the comparative physical properties of steel-mix castings and other grey cast irons, with special reference to the influence of thickness and mass.

Electric Furnace Cast Iron. C. E. Williams and C. E. Sims. (United States Bureau of Mines, 1928, Technical Paper No. 418). This Report deals in great detail with the production of cast iron in the electric furnace from steel scrap. The uses, supply, and future utilisation of ferrous scrap are discussed. A study is also made of carburisation, and the authors' experiments are described. The advantages and costs of the production of synthetic cast iron are summarised. The ability of the electric furnace to refine and superheat iron, and the superiority in many ways of electric furnace iron over cupola iron,

make the electric furnace advantageous under special conditions. In addition, the possibility of producing cast iron from cheap grades of ferrous scrap has brought the electric furnace into prominence. In the electric furnace a superior iron, having about twice the strength of ordinary cupola iron, can be made. One of the outstanding characteristics of electric furnace grey iron is its resistance to impact. These advantages in strength and toughness are due largely to the physical structure of the iron, which is fine-grained and dense.

Economic Supervision of Production in Foundries. H. Reininger. (Die Giesserei, 1928, Vol. 15, Jan. 6, pp. 10-15). The author discusses the organisation and economic control of the processes employed in foundry practice.

Addition of Silicon to Castings. M. Debar. (Fonderie Moderne, 1927, Vol. 21, Nov. 25, pp. 472-476). The advantages of silicon additions to semi-steel mixtures and grey-iron castings are discussed.

The Selection of Pig Iron and Similar Raw Materials Used in the Manufacture of Grey-Iron Castings. A. Smith. (Foundry Trade Journal, 1928, Vol. 38, Mar. 1, pp. 149-151). In dealing with the selection of foundry pig irons the author submits some sample specifications for pig irons for different purposes to show how the range of the limits to be called for should be adjusted to meet the requirements. A table is included showing how closely manufacturers can supply pig irons to reasonable specifications.

The Predetermination of the Sulphur Content of Cast Iron in Cupola Practice. B. Osann. (Die Giesserei, 1928, Vol. 15, Mar. 2, pp. 204-206). Tables are presented showing an empirical method of calculating the burden and giving the predetermination of sulphur content in cupola melting according to a method developed by the author.

The Use of Fluorspar in Cupola Practice. B. Osann. (Giesserei-Zeitung, 1927, Vol. 24, Dec. 1, pp. 659-664).

The Technique and Economics of Melting in Cupola Practice: the Theory, Art, and Psychology of Casting. J. Schumacher. (Giesserei-Zeitung, 1928, Vol. 25, Mar. 1, pp. 148-152).

The Formation of Zones in Cupolas and their influence on the Melting Process. K. Mühlbradt. (Die Giesserei, 1928, Vol. 15, Apr. 13, pp. 335-339).

Operating Experience and Results obtained with the Schürmann Cupola. E. Springorum. (Giesserei-Zeitung, 1928, Vol. 25, Feb. 15, pp. 105-113).

Metal Losses in the Foundry. (Foundry Trade Journal, 1928, Vol. 38, Feb. 23, p. 138). A brief analysis is given of the many ways in which metal losses occur in the foundry.

American Foundry Practice. (Foundry Trade Journal, 1927, Vol. 37, Nov. 10, p. 102). A brief discussion of some aspects of American foundry practice that differ from British methods.

Foundry Practice in the United States of America. E. Longden. (Paper read before the Institute of British Foundrymen: Foundry Trade Journal, 1927, Vol. 37, Dec. 29, pp. 227-231). An illustrated account is given of the latest developments in American foundry practice.

The International Foundry Exhibition in Paris, 1927. U. Lohse. (Die Giesserei, 1928, Vol. 15, Jan. 6, pp. 6-10; Jan. 13, pp. 25-28; Jan. 20, pp. 51-55; Jan. 27, pp. 78-82; Zeitschrift des Vereines deutscher Ingenieure, 1928, Vol. 72, Jan. 7, pp. 5-10). The author describes the various machines for use in foundries that were exhibited.

Handling Plant in the Foundry. (Iron and Steel Industry, 1928, Vol. 1, May, pp. 253-255). An illustrated description of several exhibits of foundry machinery which were in operation at the International Foundry Trades Congress and Exhibition, Paris, in the autumn of 1927.

Cleaning Problems. Gertreudts. (Giesserei-Zeitung, 1928, Vol. 25, Jan. 15, pp. 50-53). The author describes experiments made on the cleaning of castings by jets of water under pressure. By means of graphs, he shows the relationship between the amount of water, the pressure at which it is used, the diameter of the nozzle through which it is forced, the time necessary to clean the casting, and the cost. The technical utility and the economy of the process are not, however, discussed.

Cleaning Room Progress aids Production of Quality Castings. F. G. Steinebach. (Foundry, 1928, Vol. 56, Feb. 15, pp. 134-135; Mar. 1, pp. 179-180, 190; Mar. 15, pp. 214-216; Apr. 1, pp. 264-267, 274; Apr. 15, pp. 308-312). Various types of equipment used for the cleaning of castings are described.

Cleaning Room Merits Study. L. D. Peik. (Iron Age, 1927, Vol. 120, Nov. 24, pp. 1433-1435). A brief discussion of developments in the cleaning of castings.

New Designs of Sand-Blast Apparatus. U. Lohse. (Stahl und Eisen, 1927, Vol. 47, Nov. 24, pp. 1973-1976). Various new types of revolving sand-blast drums and tables are illustrated and described.

Skimmer Gate Keeps out Dirt. H. N. Tuttle. (Foundry, 1927, Vol. 55, Oct. 15, pp. 816-817). A simple type of pouring gate is described which may be applied to any pattern or pattern plate, and ensures a clean casting.

The Influence of Metals on Workshop and Design Problems. A. H. Goodger. (Paper read before the Manchester Association of Engineers: Foundry Trade Journal, 1928, Vol. 38, Apr. 5, p. 236). The author discusses several factors in the production of sound castings.

Rules for the Design of Grey-Iron Castings. R. Lehmann. (Die Giesserei, 1927, Vol. 14, Oct. 8, pp. 681-685; Oct. 15, pp. 701-705; Oct. 29, pp. 765-770; Nov. 5, pp. 784-790). The rules for the design of grey-iron castings formulated by the German Committee on Economic Production are discussed.

MOULDS AND CORES.

Pattern-making. A. C. Furmston. (Paper read before the Institute of British Foundrymen; Foundry Trade Journal, 1928, Vol. 38, Jan. 19, pp. 38-40). The author discusses the following features of pattern-making: materials used, auxiliary material, pattern control, core boxes, shoddy patterns, and metal patterns.

Machine Moulding. W. J. Molyneux. (Paper read before the Institute of British Foundrymen; Foundry Trade Journal, 1928, Vol. 38, Jan. 5, pp. 11-12). A brief discussion on the developments of moulding machines. The main types and makes of machines are briefly reviewed and the relative merits of compressed air, hydraulic power, and electricity in their application to machine moulding are outlined.

Progress in German Moulding Machine Construction. U. Lohse. (Die Giesserei, 1927, Vol. 14, Nov. 19, pp. 817-822; Nov. 26, pp. 833-837).

Sandless Foundry Makes Progress. H. Kimber. (Iron Age, 1928, Vol. 121, May 3, pp. 1214-1217). The results achieved by the use of long life or permanent moulds and the improvements which have been developed in practice and in the design of the machines used at the plant of the Holley Carburetor Co., Detroit, are described and illustrated. In practice the mould is first cleaned by a blast of compressed air, and is then recoated with a fresh coating of lamp-black for every casting. A special moulding machine carries 12 permanent moulds and rotates intermittently with intervals of about 3 seconds. The moulds have numerous pins cast on their back surfaces, and over

these air is passed during pouring operations to control the temperature of the mould.

The Production of Permanent Moulds for Cast Iron. K. Lehmann. (Die Giesserei, 1928, Vol. 15, Feb. 10, pp. 130-132). Particulars are given of the Büßelmann moulding process, and its advantages are pointed out.

Ramming Moulds by Sand-Slinger. D. Sharp. (Paper read before the Institute of British Foundrymen; Foundry Trade Journal, 1928, Vol. 38, Mar. 29, pp. 221-222). The author describes and illustrates the method of ramming moulds with the Beardsley-Piper sand-slinger.

Hidden Defects in Iron Castings. P. R. Ramp. (Iron Age, 1928, Vol. 121, Mar. 22, pp. 791-793, 841). The author illustrates some methods of moulding whereby hidden defects are eliminated or else confined to places where their presence is not harmful to the casting. The manner in which chaplets may cause defects in castings is also explained.

Some Experience in Practical Moulding. H. Sutcliffe. (Paper read before the Institute of British Foundrymen; Foundry Trade Journal, 1928, Vol. 38, Mar. 15, pp. 185-188). The author describes and illustrates a number of typical moulding jobs carried out in dry sand and loam.

Making Cores in the Dodge Foundry. (Foundry, 1927, Vol. 55, Nov. 15, pp. 876-878, 887). A general illustrated account of the methods and equipment employed at the Dodge Foundry for the production of moulds and cores. Conveyor units are used extensively in transporting moulds, castings, and flasks.

Sea-Sand Cores. (Foundry Trade Journal, 1928, Vol. 38, Mar. 1, p. 145). The use of sea-sand cores in the foundry is briefly discussed and the method of making a core for a typical casting is explained.

Some Further Notes on Oil Sand and Motor Cylinders. W. West. (Paper read before the Institute of British Foundrymen; Foundry Trade Journal, 1927, Vol. 37, Dec. 22, pp. 211-213). The results are given of an investigation of the use of rosin as a medium for increasing the green bond strength of an oil core mixture. The effect of mixing and milling upon the grain-size of an oil sand mixture is also dealt with.

The Mechanical Aspect of Oil Sand Cores. (Foundry Trade Journal, 1928, Vol. 38, Apr. 26, pp. 299-300). The action of liquid iron on oil sand cores is discussed, and variation in the pressure exerted by the gases in the core is shown diagrammatically.

Conveyor Type Oven Used for Baking Cores. W. W. Burden. (Fuels and Furnaces, 1927, Vol. 5, Dec., pp. 1661-1663). The author describes a continuous conveyor type of core oven, which has proved very efficient in baking cores used in casting car wheels. The oven is oil-fired and fitted with seven burners. Each burner operates in a separate combustion chamber lined with firebrick. The baking time is $2\frac{1}{2}$ hrs. at 450° F., and the cooling time, or the length of time taken for the core rack to travel from the exit end of the heating chamber to the unloading point, is $1\frac{1}{2}$ hrs.

Bakes Cores in Gas Furnace. R. G. Van Grundy. (Foundry, 1927, Vol. 55, Nov. 1, pp. 851-854). Numerous factors to be taken into consideration in the baking of cores in gas-fired furnaces are discussed. Gas as a fuel possesses numerous advantages; combustion is easily controlled, and the atmosphere can be kept oxidising, reducing, or neutral as desired. An oxidising atmosphere is required in baking cores. Temperature control can be effected through the use of direct-acting thermostats. Operating results are tabulated.

Modern Drying Stoves. G. E. France. (Paper read before the Institute of British Foundrymen: Foundry Trade Journal, 1927, Vol. 37, Nov. 17, pp. 121-123). The subject is discussed under the following headings: Evolution of the modern stove; classification of stoves; fuel available for drying stoves; underlying principles in design.

A New Type of Drying Oven. J. Mehrten. (Die Giesserei, 1928, Vol. 15, Feb. 24, pp. 180-181). Brief particulars are given of the Grocholl drying oven.

New Device Dries Moulds Electrically. R. C. Deale. (Foundry, 1927, Vol. 55, Dec. 15, pp. 974-975). A type of electric heater is described, specially designed for the skin drying of long or deep moulds. It is rated at 1250 watts at either 110 or 220 v. Another type is described which is rated at 5 kw., and is built up of a number of 500 watt space heaters. These are mounted in a frame of iron strips and angles. This type of heater is adapted to general foundry conditions, and is designed to be set in a mould without the use of any support.

MOULDING SANDS.

Scottish Moulding Sands. F. Hudson. (Paper read before the Institute of British Foundrymen: Foundry Trade Journal, 1928, Vol. 38, Apr. 12, pp. 262-266; Apr. 19, pp. 279-281). A practical paper describing methods of testing moulding sands and giving the results of tests on a variety of Scottish sands.

Simplify Foundry Sand Tests. T. F. Kiley and T. W. Peterson. (Foundry, 1927, Vol. 55, Nov. 15, pp. 888-889). A brief illustrated description is given of a machine for testing the compressive strength of foundry sand.

Describes Sand Test Methods. A. Kessner. (Paper read before the Verein deutscher Eisengiessereien Giessereiverband: Foundry, 1928, Vol. 56, Feb. 15, pp. 144-148). The author describes methods of testing by which the density, bonding strength, and permeability of sand are determined on samples taken from moulds made under operating conditions.

Sand-Condition Plant Saves Labour. (Iron Age, 1927, Vol. 120, Dec. 1, pp. 1512-1513). A brief illustrated account is given of a plant for the preparation of foundry sand in operation in an American grey-iron foundry.

Practical Moulding Sand Control. N. D. Ridsdale. (Foundry Trade Journal, 1927, Vol. 37, Nov. 3, pp. 79-82). The author deals mainly with greensands such as are used for iron and brass founding, and indicates the nature and value of small scale tests both within and without the laboratory for assisting the practical moulder to use sand to the best advantage. Prominence is given to tests of sufficiently simple kinds which can be carried out by the moulder in the foundry, without necessarily requiring the services of a specially trained technical man.

Observations on the Subsidence Test for Moulding Sands. J. L. Francis. (Iron and Steel Industry, 1928, Vol. 1, Mar., pp. 171-172). In this test, devised by J. E. Fletcher, a quantity of the carefully dried and sieved sand is fed into a long test-tube; cold freshly boiled tap water is added to fill the tube. After shaking thoroughly it is found that the water no longer fills the tube, so giving a measure of the voids between the sand and silt grains, which is a useful index of the type and openness of the grain packing and also, approximately, of the gas permeability of the sand. The present article indicates certain weak points in the test. In filling the tube some "additional" air always becomes entrapped in the sand; this may be removed by gentle tapping, but then the grains may be shaken together too much and so give too low an index on testing. Acting in the opposite direction is the premature escape of air from the sand before the tube is agitated. Modifications of the test to meet these criticisms are suggested.

Sand Milling and Handling. H. F. Coggon. (Paper read before the Institute of British Foundrymen; Foundry Trade Journal, 1927, Vol. 37, Dec. 1, pp. 153-156). The various methods of mixing and handling sand are described.

A New Method of Testing Moulding Sand. W. Reitmeister. (Giesserei-Zeitung, 1927, Vol. 24, Nov. 15, pp. 621-629).

Method for Testing the Compressibility of Dry Moulding Sand. W. Reitmeister. (Die Giesserei, 1928, Vol. 15, Mar. 16, pp. 245-248).

Control of Foundry Operations by Appropriate Testing of Rammed Moulding Sand. A. Rodehüser. (Die Giesserei, 1928, Vol. 15, Apr. 13, pp. 329-335).

SPECIAL CASTINGS.

Chilled Iron Rolls. A. Allison. (Foundry Trade Journal, 1928, Vol. 38, Apr. 12, pp. 259-261; Apr. 19, pp. 277-278). The production of chilled iron rolls is reviewed, and methods of producing rolls with lower carbon contents are described. Oil furnace melting and various manipulations are discussed. Conclusions indicated are, that not only is depth of chill a function of total carbon and silicon, but also that graphite precipitation is more gradual with a lower ratio of carbon to silicon. Indications are given of the relation of analysis to chill depth. Manganese sulphide is considered to be thrown out of solution in the molten iron between temperatures of 1350° and 1250° C. The limits of carbon contents for chilled rolls for various service conditions are indicated. The effect of chill depth upon length of service, and also the cause of blemishes, are considered. Suggestions for standardisation are put forward.

The Use and Abuse of Chilled Rolls. W. H. Melaney. (Blast-Furnace and Steel Plant, 1928, Vol. 16, Jan., pp. 12-15). The manufacture of chilled rolls is briefly described and their structure and physical properties are discussed. The care of rolls in service is also touched upon, and space is devoted to the use and abuse of steam for the purpose of preventing the roughening of the roll surface when heavy sheets are being rolled or the mill is being pushed.

Hollow Rolls of Treated Cast Steel. (Aciers Spéciaux, 1927, Vol. 2, Oct., pp. 557-558). The merits of cast and forged rolls are briefly discussed, and the advantages of hollow cast rolls, introduced by the A.R.B.E.D. company, are described. A special material is stated to be used for the core, and the roll is cast in sand, but no details of manufacture are given.

High Chromium Cast-Iron Rolls. J. F. Kayser. (Foundry Trade Journal, 1928, Vol. 38, Feb. 9, p. 94). A brief discussion of melting

and moulding practice for the production of chilled rolls of chromium cast iron. The composition usually favoured is as follows : carbon 3·5, silicon 0·7 to 1·0, manganese 0·3, chromium 15, nickel 0·5, sulphur 0·04, and phosphorus 0·03 per cent. During the last few years for some purposes the above analysis has been completely modified. The carbon has been reduced to as low as 1·4 per cent., the chromium to 12 per cent., and 1 per cent. each of cobalt and molybdenum have been added. There is no direct evidence that this latter composition gives a better product than the former. Neither of these high-chromium irons can be satisfactorily melted in a cupola, and it is necessary either to melt them in electric furnaces, Siemens furnaces, or in crucibles. The metal is cast at as low a temperature as possible into cast-iron moulds, and it is advisable to heat the moulds and then paint them with tar. Slow cooling of the castings is recommended. After machining the rolls are hardened by quenching in oil from 980° to 1000° C. The hardness will then be 600 Brinell.

The Manufacture of Cast-Iron Tubbings for Mine Shafts. H. Becker. (Technische Blätter : Foundry Trade Journal, 1927, Vol. 37, Nov. 10, pp. 107-108).

High-Silicon Cast Iron or Acid-Resisting Iron. E. Whitaker. (Paper read before the Institute of British Foundrymen : Foundry Trade Journal, 1928, Vol. 38, Mar. 15, pp. 189-190). A brief discussion on the composition and manufacture of acid-resisting castings.

The Moulding and Casting of Small Pulleys and Gear Blanks. J. Longden. (Paper read before the Institute of British Foundrymen : Foundry Trade Journal, 1928, Vol. 38, Mar. 22, pp. 205-210). The author describes in some detail the methods of moulding these castings, and discusses the factors governing their strength and soundness.

Making a Test Column Casting. F. C. Edwards. (Foundry Trade Journal, 1928, Vol. 38, Mar. 29, pp. 219-220). The author describes and illustrates the method adopted for making a casting in greensand 10 ft. long, 3 ft. square, and weighing about 4 tons.

Making Cast-Iron Pipes at the "New" Works, Staveley Coal and Iron Co., Ltd. (Foundry Trade Journal, 1928, Vol. 38, Feb. 23, pp. 129-131). An illustrated account is given of the methods and equipment employed for the manufacture of cast-iron pipes.

New Method of Making Cast Pipe. (Iron Age, 1928, Vol. 121, Apr. 12, pp. 999-1003). Illustrated particulars are given of the method of moulding cast-iron pipe at the works of the McWane Cast Iron Pipe Co., Birmingham, Alabama. Hand-labour has been eliminated by the substitution of mechanical equipment.

Specialises in Cast-Iron Pipe for well over a Century. P. Dwyer. (Foundry, 1928, Vol. 56, Apr. 1, pp. 246-250). A general illustrated account of the methods employed for the moulding of pipes at the plant of R. D. Wood & Co., Florence, New Jersey.

Sugar Mill Castings made in Loam. (Foundry, 1928, Vol. 56, Mar. 1, pp. 176-178). A brief illustrated account of the methods employed in an American foundry for moulding castings used in the construction of sugar mill evaporators. These castings are large in area but comparatively light in section and must present a clean smooth surface and be homogeneous throughout to withstand a water test.

Casting Radiators Continuously. J. B. Nealey. (Iron Age, 1928, Vol. 121, Apr. 26, pp. 1144-1146). An illustrated account is given of a method for the continuous casting of radiators. The machine consists of two large annular rings set close together, one for moulding and the other for pouring. The first is made of two cast-iron rings, joined together to form a circular frame 15 ft. in diameter. This frame is set on rollers and is rotated by motors. Moulding machines are mounted on this frame at intervals, and when rotated each machine passes successive workmen, each performing some operation until the flask is made up. The flask is then transferred to the pouring ring, where the pouring and shake out take place. The pouring ring is similar in construction to the other, but is 25 ft. in diameter; the increased size is to give a sufficient cooling period between pouring and shaking out.

Radiator Foundry requires Exacting Sand Control. F. G. Steinebach. (Foundry, 1927, Vol. 55, Dec. 1, pp. 912-918, 931). The methods and equipment employed at the plant of James B. Clow & Sons, Newcomerstown, Ohio, for the production of radiators are illustrated and described in detail. The plant contains a number of interesting features, including a special sand-handling and preparing unit, special rigs for pouring and shaking out the castings, and special moulding equipment.

Uses Direct Metal for Ingot Moulds. (Foundry, 1927, Vol. 55, Nov. 15, pp. 882-886). The layout and equipment of the plant of the Valley Mould and Iron Corporation, Hubbard, Ohio, for the production of ingot moulds are described and illustrated. Particulars are given of the methods of moulding and core-making. An outstanding feature of the plant is the use of direct metal from blast-furnaces for pouring the castings. The moulds are dried by means of oil-burning torches, and the cores in an oil-fired furnace.

CENTRIFUGAL CASTING.

The Arens Centrifugal Tube-Casting Process at Choindez. (Röhren-industrie, 1928, Vol. 21, May 24, pp. 228-229). The machine is described and tests on the tubes cast in it are recorded. The particular feature of the machine is that the mould is cooled by external jets of water.

Spins Pipe in Iron Moulds Lined with Sand. P. Dwyer. (Foundry, 1928, Vol. 56, Feb. 15, pp. 125-131, 156). The centrifugal casting of pipes in sand-lined iron moulds as carried out at the plant of R. D. Wood & Co., Philadelphia, is described and illustrated. The method of casting is based on the same principle as the De Lavaud process, the outstanding difference being the use of the sand-lined moulds, eliminating the necessity for annealing the castings.

Centrifugal Castings for Diesel Engines. J. E. Hurst. (Paper read before the Diesel Engine Users Association, Nov. 25, 1927). A discussion of the Hurst-Ball centrifugal casting process as applied to the production of internal-combustion engine castings.

STEEL FOUNDRY PRACTICE.

Electro-Metallurgy of Steel for Foundry Use. R. J. Richardson. (Paper read before the Institute of British Foundrymen: Foundry Trade Journal, 1928, Vol. 38, Jan. 26, pp. 61-64). The outstanding events in the development of the electric furnace are reviewed, the arrangement of a modern furnace is outlined, and the following subjects are discussed: furnace linings, basic practice, removal of the elements, refining slag, acid practice, reducing acid conditions, acid versus basic electric steel.

Steel Foundry Practice. A. D. Kirby. (Paper read before the Institute of British Foundrymen: Foundry Trade Journal, 1927, Vol. 37, Nov. 24, pp. 144-146). The nature of the sands employed and the methods of moulding used in steel foundry practice are discussed. The manufacture of steel in the Tropenas converter is also dealt with.

Over-Expansion in Steel Foundries. W. J. Corbett. (Iron Age, 1928, Vol. 121, Jan. 5, pp. 35-36). There are 293 individual plants in the United States in which steel castings are manufactured, and these are operated by 267 companies. The total practical capacity for the manufacture of steel castings in the United States is 198,863 net tons per month, or 2,320,000 tons per annum.

The trend in production of basic open-hearth steel castings made in foundries has been upward. The annual production of acid open-hearth steel castings is strikingly parallel to that of basic open-hearth castings, and nearly equal in quantity. The decline in converter castings is due entirely to the supplanting of converters by electric furnaces and small open-hearth furnaces. Under certain conditions converters are slightly more costly for making steel, and severe competition has compelled steel foundries to replace them with other types if there was a probability of reducing costs by doing so. This condition has not existed in all installations, since economic factors vary.

Giant Steel Castings Dominate Power Project. (Foundry, 1927, Vol. 55, Dec. 15, pp. 950-954). Particulars are given of the heavy steel castings used in the construction of the Conowingo dam and power house. The method of moulding the large butterfly valves at the plant of the Otis Steel Co. is illustrated.

Steel Foundry Practice. L. Treuheit. (Paper read before the Verein deutscher Stahlformgiessereien, Oct. 22, 1927: Giesserei-Zeitung, 1927, Vol. 24, Dec. 15, pp. 684-685). The influence of the mould and mould material on the successful casting of complicated patterns, investigations of the mould material, mixtures, additions, synthetic moulding sands, and experiments on the packing of sand in moulding machines, are described and discussed.

Steel-Making, with Special Reference to the Manufacture of Steel Castings. J. Deschamps. (Paper read before the Institute of British Foundrymen: Foundry Trade Journal, 1927, Vol. 37, Nov. 17, pp. 125-127). The author describes briefly the various processes in use in steel foundries for the production of plain carbon steels, and discusses their respective merits and disadvantages. The influence of elements on the physical properties of steel is outlined.

Steel Foundry Practice. P. Longmuir. (Iron and Steel Industry, 1928, Vol. 1, Jan., pp. 119-120; Mar., pp. 181-182; Apr., pp. 211-213). The continuation of a series of articles (*see* Journ. I. and S.I., 1927, No. II. p. 537). In the present numbers the acid, neutral, and basic refractories used in open-hearth practice are dealt with. The working of an acid open-hearth heat is next described, and the various operations are discussed.

The Fiat Furnace in the Steel Foundry. E. Widdel. (Zeitschrift des Vereines deutscher Ingenieure, 1927, Vol. 71, Dec. 17, pp. 1785-1789). The conversion of a Bessemer works with small converters to an electric furnace plant is described, and full details of the Fiat electric furnace and its equipment are given. Figures relating to the operation of the furnace are briefly reported.

The Present-Day Condition of the Electric Melting Furnace in the Iron Industry. K. von Kerpely. (Giesserei-Zeitung, 1928, Vol. 25, Mar. 1, pp. 135-147). The development of the production of electric steel and the principal types of electric furnaces are discussed. Various plants and their electrical equipment are described, and notes are given on the latest American and German systems of electrical connection. Modern high-production furnaces are also dealt with.

Electric Melting. H. S. Primrose. (Paper read before the Institute of British Foundrymen: Foundry Trade Journal, 1928, Vol. 38, Feb. 2, pp. 81-84). The author discusses electric furnace practice, with special reference to the use of electric furnaces in foundries. The various types of Héroult furnaces and their suitability for use for certain classes of work are outlined, and operating results obtained with Ajax-Wyatt and Ajax-Northrup furnaces are given.

Tests and Operating Results with the Schury Oil-Fired Open-Hearth Furnace. H. Fuchs. (Die Giesserei, 1927, Vol. 14, Dec. 17, pp. 895-897).

A Tilting Regenerative Furnace for Foundry Work. Hesse and H. Pinsl. (Die Giesserei, 1928, Vol. 15, Mar. 30, pp. 281-289).

Pioneering the Jobbing Trail. (Foundry, 1928, Vol. 56, Feb. 1, pp. 84-89). A general illustrated description of the plant and methods employed by the Lebanon Steel Foundry, Lebanon, Pa., for the manufacture of steel castings.

MALLEABLE CAST IRON.

Some Methods of Production in a Modern Malleable Iron Foundry. A. J. Beck. (Paper read before the Institute of British Foundrymen: Foundry Trade Journal, 1928, Vol. 38, Jan. 5, pp. 7-9). An account is given of the machines and methods employed at the foundry of Leys Malleable Castings Co., for the production of various types of malleable iron castings, which are illustrated.

Malleable Melting Practice. A. J. Grindle. (Foundry, 1928, Vol. 56, Feb. 15, pp. 139-142). Furnace design, character of the charge, refractories, analyses of the metal, and other features are discussed in connection with the use of pulverised fuel.

Metal for Malleable Iron Fittings Melted in the Cupola. L. E. Gilmore. (Foundry, 1927, Vol. 55, Nov. 1, pp. 840-843). The author discusses cupola practice for the production of black-heart malleable

iron fittings of thin section. A typical charge is made up as follows : sprue, 40 per cent. ; malleable scrap, 20 per cent. ; iron, 20 per cent. ; steel, 20 per cent. ; spiegel, 0.75 per cent. Melting loss in silicon averages from 0.10 to 0.15 per cent., and in manganese from 0.15 to 0.25 per cent. Phosphorus remains practically as charged. Sulphur will increase about 0.06 to 0.12 per cent., and if desired some of this may be eliminated by treating the iron in the ladle with soda ash or caustic soda. Three factors determine the amount of carbon in chemical combination in the white iron : percentage of silicon present in relation to the carbon ; casting temperature ; and the rate of cooling. Under usual foundry conditions a silicon between 0.60 and 1 per cent. will produce good malleable iron ; the iron with silicon content under 0.80 per cent. is more likely to be the stronger and tougher product.

Anneal Each Heat Independently. B. Finney. (Iron Age, 1928, Vol. 121, May 3, pp. 1209-1213). The practice of the Southern Malleable Iron Co., East St. Louis, Illinois, for the annealing of malleable castings is described and illustrated. The annealing cycle for the castings from each heat is scheduled after an analysis of the iron has been made. Consequently the heat treatment is made to vary according to the requirements necessary to produce a perfect casting. Melting and moulding practice is also discussed. In the moulding operation a special vent board is used to eliminate pinholes in the castings. This consists of a board or other backing, which may or may not be part of the flask, fitted with a number of venting pins or wires.

FOUNDRY PLANT.

Southern Foundries. (Foundry Trade Journal, 1928, Vol. 38, Apr. 5, pp. 237-239). An illustrated account is given of the methods and equipment employed at the plant of Southern Foundries, Ltd., Croydon. The melting plant consists of three cupolas, the largest of which is 7 ft. diam., and melts at the rate of 16 tons per hr.

The Quantity Production of Castings. A. S. Beech. (Paper read before the Institute of British Foundrymen : Foundry Trade Journal, 1927, Vol. 37, Dec. 8, pp. 177-181). An illustrated description is given of the layout of French and Spanish equipment for the continuous production of castings.

Buick Foundry Meets Peak Load Needs. P. Dwyer. (Foundry, 1927, Vol. 55, Nov. 1, pp. 830-835). **Mechanical Equipment Handles Sand in New Buick Foundry.** P. Dwyer. (Foundry, 1927, Vol. 55, Dec. 1, pp. 924-931). **700 Tons Daily Melt of Auto Shop.** P. Dwyer.

(Foundry, 1928, Vol. 56, Jan. 1, pp. 7-14). **Speed Marks Cleaning Procedure in New Buick Plant.** P. Dwyer. (Foundry, 1928, Vol. 56, Feb. 1, pp. 99-104). A series of articles describing the methods and equipment employed in the grey-iron foundry recently placed in operation by the Buick Motor Co., Flint, Michigan. The first and second articles deal with the general features of the plant, and describe the methods of moulding and sand-handling. The third article deals with the melting and core-making departments. The concluding article describes the methods and equipment used for cleaning castings.

Piston Moulding Conveyor Units. (Iron Age, 1927, Vol. 120, Dec. 8, pp. 1582-1583). Illustrated particulars are given of the piston moulding equipment at the foundry of the Buick Motor Co. It consists of two complete mould conveyors and hooded cooling conveyors, with two lines of moulding machinery served by a single sand-handling and preparing system.

Exceptional Conveyor Equipment. F. L. Prentiss. (Iron Age, 1927, Vol. 120, Nov. 3, pp. 1217-1223). An illustrated account is given of the extensive use of conveying equipment at the grey-iron foundry of the Buick Motor Co., Flint, Mich. An inclined conveyor is used for the transport of cores. The cores are loaded into moving racks with several shelves, the first cores being placed on top. As the conveyor moves down the line between the core benches it rises, so that the core-makers may place cores on the bottom shelves more conveniently.

Moderate Size Plant Modernises. (Iron Age, 1928, Vol. 121, Jan. 19, pp. 187-190). An illustrated account is given of the layout of the overhead conveying system at the plant of the American Foundry Co., Indianapolis.

Foundry Output Increased by Sand-Handling Equipment. G. A. Gunther. (Iron Age, 1927, Vol. 120, Dec. 15, pp. 1645-1649). The author gives an illustrated description of the continuous moulding and sand-handling equipment at the South Bend plant of the Studebaker Corporation. It is a combination of conveying, elevating, and sand-conditioning units so arranged that none of the sand is man-handled. Stripping machines are mounted on turntables, which bring the flasks within range of a sand-slinger, and then delivers them to the mould conveyor.

Power Conveyors Handle Large Moulds. (Foundry, 1927, Vol. 55, Dec. 15, pp. 962-965; 1928, Vol. 56, Jan. 1, pp. 22-24, 41). A detailed illustrated account of the manufacture of castings at the plant of the American Abrasive Metals Co. The first article describes the mould conveyors, and the second the cleaning operations and the sand-handling and preparing equipment. At this plant iron castings,

surfaced with an abrasive material, are produced. A thin layer of ground carborundum or other material is sprinkled on the mould just before pouring, and the abrasive particles are picked up by the metal, forming an integral part of the casting.

Stove Plant is Synchronised Machine. P. Dwyer. (Iron Trade Review, 1928, Vol. 82, Apr. 12, pp. 946-948; May 3, pp. 1130-1133). The equipment of the foundry at the new stove plant of the Peninsular Stove Co., Detroit, is described and illustrated.

The Layout of Foundry Plants. K. Irresberger. (Die Giesserei, 1928, Vol. 14, Oct. 1, pp. 666-671; Oct. 8, pp. 685-690; Oct. 15, pp. 705-708).

COOLING PHENOMENA AND DEFECTS IN CASTINGS.

Notes on Rate of Cooling and Casting Temperature. (Foundry Trade Journal, 1927, Vol. 37, Oct. 27, pp. 71-72; Dec. 1, pp. 157-158). The work of various investigators on the influence of rate of cooling and casting temperature on the properties of metals is summarised.

The Influence of Metals on Workshop and Design Problems. A. H. Goodger. (Paper read before the Manchester Association of Engineers: Iron and Coal Trades Review, 1928, Vol. 116, Mar. 30, p. 459). The cooling of castings in moulds, dissolved gases in metals, effect of casting temperature, and test-bars and the testing of castings, are discussed.

Methods of Measuring Contraction. H. C. Dews. (Foundry Trade Journal, 1927, Vol. 37, Dec. 1, p. 162). Methods of measuring the volume changes in castings used by different investigators are briefly discussed.

Piping in Relation to the Eutectic Composition. B. Osann. (Die Giesserei, 1928, Vol. 15, Jan. 20, pp. 49-51). The author puts forward a new hypothesis to the effect that eutectic alloys should not give rise to piping. He bases his arguments on the well-known Lanz process for casting pearlitic iron, in which the moulds are preheated before casting. It is claimed for "perlit" that it is peculiarly free from piping; the author shows that this characteristic cannot be due to the preheating of the moulds, and he puts forward data to show that the metallographic structure is the sole cause of its freedom from piping.

The Graphite Eutectic in Cast Iron. E. Schüz. (Die Giesserei, 1928, Vol. 15, Jan. 27, pp. 73-78; Feb. 3, pp. 102-108). The historical

development of the various conceptions concerning the phenomena taking place during cooling in irons rich in carbon is reviewed, the first observation and first systematic production of grey cast iron with eutectic graphite (perlit iron) in the foundry is described, and modern ideas on the separation of the graphite from the molten metal are discussed.

Maurer's Cast-Iron Diagram at Different Cooling Rates. E. Maurer and P. Holtzhausen. (Stahl und Eisen, 1927, Vol. 47, Oct. 27, pp. 1805-1812; Nov. 24, pp. 1977-1984; *abstract*, Foundry Trade Journal, 1927, Vol. 37, Dec. 29, pp. 232-224). Melts were cast in cold moulds, in moulds preheated to 250°C., in moulds preheated to 450°C., and were also cast into moulds to produce thin wall castings. The influence of these various conditions on Maurer's diagram of the structure is shown.

Cooling Tests on Various Cast-Iron Specimens. F. Roll. (Giesserei-Zeitung, 1928, Vol. 25, Mar. 1, pp. 153-155).

Shrinkage of Steel Castings. F. Körber and G. Schitzkowski. (Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1927, Vol. 9, pp. 279-294; Stahl und Eisen, 1928, Vol. 48, Feb. 2, pp. 129-135; Feb. 9, pp. 172-178; *abstract*, Metallurgist, 1928, Apr. 27, pp. 55-56). The course of the shrinkage in steel castings in cooling from the point of solidification down to room temperature was followed, using plain cast steel bars, and bars having flanges cast on their ends, both basic and acid open-hearth steel being taken for the tests. All those castings in which shrinkage was impeded showed cracks immediately after cooling below the point of solidification at about 1300° C. Tests were then made on fairly large steel castings such as T-pieces of pipe, belt pulleys, motor casings, and cylinders. Shrinkage cracks were found on many, where chaplets had been wrongly placed, or if a too unyielding sand or an unsuitable composition of the metal had been used. In casting large disc wheels, it has been found very effective to give the disc a conical form. The best and very usual method for avoiding shrinkage cracks is to loosen or break up the mould immediately the metal has set—i.e. before it cools below the critical point of 1300° C. Thin castings are likely to reach this temperature within one minute after pouring. If the thickness is 2 in. or over, 6 to 8 minutes can be allowed.

Shrinkage Stresses in Steel Castings. H. Malzacher. (Stahl und Eisen, 1927, Vol. 47, Dec. 15, pp. 2108-2112).

Shrinkage Holes in Small Grey Iron Castings. P. A. Russell. (Paper read before the Institute of British Foundrymen: Foundry Trade Journal, 1928, Vol. 38, Jan. 26, pp. 55-59). The author discusses the

formation of shrinkage holes or "drawing" in castings, and means for their prevention. It is concluded that the cause of drawing in grey iron castings is that the expansion due to the formation of graphite is practically all absorbed in expanding the outer shell of the casting, and the remaining liquid metal shrinks. The amount of drawing in a casting is governed by the following, the conditions stated being those which tend to reduce the amount of drawing : (a) The composition of the metal (low silicon, low phosphorus, high manganese, and medium total carbon are ameliorative) ; (b) rapid uniform freezing of the metal as governed by the mould size and conditions ; (c) the feeding of fresh liquid metal into the casting by means of runners and risers, and the increased efficiency of these due to high casting temperature ; and (d) the provision of means for the ready escape of the mould gases.

Liquation Causes Scabs. D. Rogers. (Foundry, 1927, Vol. 55, Dec. 15, p. 977). The author discusses the probable cause of a defect which occurs in the rectangular ingot moulds used in the tinplate industry of South Wales. These moulds generally are cast with a solid bottom, and the defect takes the form of a slightly rough film with blacking on both sides of it, which generally appears on the corners of the core. Sometimes it is spread across the flat sides. The films are difficult to remove because they are attached to the casting by numerous pin-points. The author is of the opinion that the defects are due to a liquation of phosphide-rich metal which is forced out into the space between the core and the solid metal.

What Causes Dirty Castings. W. F. Prince. (Foundry, 1928, Jan. 1, Vol. 56, pp. 19-20). A discussion of the origin of defects in castings. It is pointed out that agitation of the molten iron in the mould is one of the chief causes of the formation of slag or kish on castings.

PRODUCTION OF STEEL.

STEEL-MAKING PROCESSES.

The Use of High-Class Swedish Iron in the Manufacture of Crucible Steel. (Iron and Steel Industry, 1928, Vol. 1, May, p. 249). A short note on the production of crucible steel.

Aspects of the Construction of Small Converters. E. Piwowarsky. (Die Giesserei, 1928, Vol. 15, Apr. 6, pp. 314-315). The important influence of the shape and dimensions of the converter body upon the durability of the lining, on the distribution of the blast and on the duration of the heat, on the amount of converter waste and the efficiency of the blowing machines is discussed, and the details of half a dozen typical small converter bodies are tabulated. The type of small converter in greatest use in Germany is that of Zenzes, which is briefly described.

Presidential Address. B. Talbot. (Iron and Steel Institute, Annual Meeting, May 1928; this Journal, p. 33). The developments in the design of open-hearth furnaces are reviewed. The address contains the first published account with a drawing of the new 180-ton Talbot furnace with auxiliary hearths, now in operation at Cargo Fleet.

Calculations of the Siemens-Martin Furnace. E. Lubojatzky. (Feuerfest, 1928, Vol. 4, Feb., pp. 20-23; Apr., pp. 51-54; May, pp. 65-71). The paper deals first with a review of the general factors to be considered in the design of the various parts of a Siemens-Martin furnace. The calculation of the dimensions of the hearth—such as the length and breadth, the height of the hearth chamber—of the cross-sections and inclinations of the ports, and of the mains connecting the regenerators to the reversing valves in relation to the draught, is next considered. Finally, the qualities required in the materials of the furnace to enable them to withstand the conditions of service are discussed, and the standardisation of the structural materials is touched upon.

Modern Open-Hearth Furnaces. J. Seigle. (Technique Moderne, 1927, Vol. 19, Oct. 15, pp. 641-647). The author presents a general review of recent practice in the design and operation of open-hearth furnaces on the Continent and in America.

Outstanding Open-Hearth Improvements. C. W. Veach. (Blast-Furnace and Steel Plant, 1928, Vol. 16, Jan., pp. 34-37). A summary is given of the modifications introduced in open-hearth furnace practice and design in the United States during 1927.

Changes in Open-Hearth Design and Practice during 1927. W. J. Priestley. (Iron Age, 1928, Vol. 121, Jan. 5, pp. 37-39). Progress made during the past year in the American open-hearth steel industry is reviewed.

Open-Hearth Furnaces. A. V. Kemp. (Paper read before the Cleveland Institution of Engineers, Mar. 5, 1928). A comparison is made of tilting and fixed types of open-hearth furnaces, and the advantages of the tilting type are pointed out. The life of the tilting furnace is longer than that of the fixed type, and during such life it produces steel at a greater rate, hence the upkeep costs are lower.

Improved Open-Hearth Furnace Regenerators. J. Tornblad. (Fuel Economist, 1927, Vol. 3, Nov., pp. 82-85). The arrangement of the Kuhn regenerator chambers for open-hearth furnaces is described and illustrated. The advantages of the system are pointed out, and results obtained from a 60-ton tilting furnace equipped with this system of regenerator chambers are shown. In this system the checker brickwork is distributed in several chambers. The first chamber connects the slag chamber with the main regenerator chamber, and is the only part of the system that requires repairs from time to time. In this chamber the slag carried over from the furnace is dropped and a sloping bottom allows the slag to run into the slag chamber, from which it is periodically drawn off. The first chamber is filled with heavy checkers set wide apart, and the main regenerator chambers are filled with checker bricks of a smaller sectional area but larger heating surfaces. The gas regenerator chambers are filled with checker brickwork in proportion to the temperature of the gas that is to be reheated. According to the height of the checker-work the waste gases are cooled down to about 400° C. when passing through the main chamber. The chief advantages of the system are: decreased fuel consumption; long life of furnaces; and elimination of waste-heat boilers.

Preheaters for Open-Hearth Furnaces and their Relation to Waste-Heat Boilers. W. Dyrssen. (Mining and Metallurgy, 1928, Vol. 9, Jan., pp. 12-17). A combination of a heating system in an open-hearth furnace, consisting of an efficient metal preheater and checker chambers of the ordinary construction, is fundamentally sound. In such a system the air would be preheated in the metal preheater by using the waste gases which have passed through the checker chambers. Further

heating of the combustion air to very high temperatures would be accomplished in the checker chambers by using the waste gases directly from the melting chamber. Comparison is made of the temperature conditions in and performance of open-hearth furnaces with and without the air preheater. With an air preheater the gain in temperature of the hot air is about 250° F., resulting in an increased production of 11 per cent. and a decrease in fuel consumption of 11 to 15 per cent. The author describes and illustrates the principal features of the Blaw-Knox continuous regenerative air preheater. It consists of three chambers in which the heating elements, consisting of steel sheets, are arranged vertically. The chambers are provided with valves on the top and bottom for regulating the flow of gas and air. The author considers the relation of the preheater to the waste-heat boiler. Wherever steam is required it is his opinion that the waste-heat boiler is justified, and will pay handsome returns on the investment regardless of the use of a preheater.

Metal Air Heater for Industrial Furnaces. W. Dyrssen. (Iron and Steel Engineer, 1928, Vol. 5, Feb., pp. 81-88).

Recuperators Applied to Open-Hearth Furnaces. W. H. Fitch. (Mining and Metallurgy, 1928, Vol. 9, Jan., pp. 17-18). The author is of the opinion that possibly one-half to two-thirds of the checkers in an open-hearth furnace can be dispensed with when proper recuperators are installed. A plan is shown of a recuperative open-hearth furnace.

The Isley Furnace Control. G. A. Merkt. (Mining and Metallurgy, Dec. 1927, pp. 502-507). The Isley control apparatus as applied to open-hearth furnaces is described and the results obtained are presented. It consists of two separate Venturi-type ejector tubes, connected with the flues from the two ends of the furnace and its intervening checker chambers, one tube for each end. Each tube contains a blast pipe and is served by a low-pressure fan. One fan exhausts the outgoing gases, the other fan furnishes the air for complete combustion. Reversals are carried out by a switching arrangement on the charging floor in the immediate vicinity of the fuel switches. The flues between the tubes and the checkers serve as recuperators and preheat the ingoing air on reversal of the furnace. It is claimed that the substitution of a Venturi throat for an ordinary chimney permits a positive adjustment of draught and leads to a better heat recovery.

The Open-Hearth Furnace in Leash. G. A. Merkt. (Blast-Furnace and Steel Plant, 1928, Vol. 16, Jan., pp. 41-45). A description is given of the Isley furnace control apparatus as applied to open-hearth furnaces.

The Moll-Demag Open-Hearth Furnace. E. Schwenzner. (Iron and Steel Industry, 1927, Vol. 1, Dec., pp. 91-92). In the furnace the air and gas are mixed together before they enter the hearth, rather like the air-gas mixture in a Bunsen burner. The air regenerators are made very large and are placed at the outside ends of the furnace; air temperatures of 1400° C. (2552° F.) have been measured. The result is an intensely hot flame, consequently the charge is melted more rapidly and is sooner covered by the slag layer which protects it from the furnace gases. A slag pan is used instead of slag pockets. The furnace is claimed to be more economical in operation than the ordinary type of open-hearth, and to require fewer, cheaper, and more rapidly effected repairs.

The Temperature Fluctuations in the Gases flowing through the Open-Hearth Furnace. E. Herzog. (Stahl und Eisen, 1928, Vol. 48, Jan. 5, pp. 8-11). The rise and fall of temperature in the open-hearth furnace on reversing the gas and air were determined by pyrometer readings taken at many positions in the furnace, and the results are plotted in the form of a diagram. Mathematical calculations of the heat absorbed and given out in intermittently working heat exchangers are presented.

Investigation of the Combustion Conditions in Open-Hearth Furnaces. (Stahl und Eisen, 1927, Vol. 47, Dec., pp. 2222-2224). This article is a summary of a report by G. Neumann on an investigation of the flow of gases and their temperatures through a 40-ton tilting-furnace (the full report appeared in Archiv für das Eisenhüttenwesen, 1927, Vol. 1, Aug., pp. 111-118), and of two earlier reports by S. Schleicher and F. Lüth. Four furnaces in all were investigated, two being of the ordinary tilting type, one was a Maerz furnace, and the fourth was a Moll furnace. Samples of gas were drawn off at different levels along the length of the furnace chambers and these were analysed, in order to discover and plot the composition and temperatures of the gases burnt and unburnt, and thus to show how combustion progresses. Suggestions are made as to improvements in furnace design, and deductions are drawn as to the advantages of double gas and air ports and single gas and air ports and the design of furnace best suited for either kind of arrangement. The investigations extended to the temperature conditions in the regenerators and the effect of temperature on the gas flow through the checkers.

Investigations concerning the Carbonaceous Additions to the Fuel in Acid Open-Hearth Furnaces Heated with Mixed Gas. F. Stein. (Archiv für das Eisenhüttenwesen, 1928, Vol. 1, Apr., pp. 629-636). The investigation was made on the open-hearth plant of the Ruhrort Meiderich Works, consisting of five furnaces with a total monthly output of 25,000 tons of ingots. Furnaces I. to IV. worked with natural

draught, whilst furnace V. was run with forced draught. All furnaces had slag pockets. One of them was a 60-ton Maerz furnace, one a 70-ton tilting furnace, and the others were stationary of the ordinary type, the dimensions being stated in each case. These furnaces were all heated with a mixture of producer-gas, blast-furnace gas, and coke-oven gas. The trials were directed to discovering the effect of using liquid carbon-containing agents, tar and tar oil being chosen for the purpose.

The charge consisted of 20 per cent. cold pig, 50 per cent. scrap from the works, and 30 per cent. bought scrap. The use of a straight mixture of blast-furnace and coke-oven gas was a failure, as the non-luminous flame did not radiate sufficient heat to heat up the bath after melting down.

The addition of producer-gas remedied this difficulty and the furnaces worked well with a mixture of rich gas (coke-oven gas : blast-furnace gas + producer-gas as 1 : 2) for melting down, and a lean gas (coke-oven gas : blast-furnace gas + producer-gas as 1 : 3 up to 1 : 4) for boiling and finishing.

Trials were then made with tar oil in place of producer-gas, the oil being sprayed into the straight mixture of coke-oven and blast-furnace gas. A perfectly good result was obtained, using about 4 kg. of oil per ton of steel produced. Tar answered equally well, the consumption being 5.5 kg. of tar per ton of steel. But with tar the spraying nozzles have to be frequently cleaned and the pipes and valves require to be steam-heated to prevent clogging. Otherwise the furnace works efficiently and without overheating of the roof or ends, and a considerable economy results from dispensing with producer-gas.

Basic Open-Hearth Practice. G. B. Waterhouse. (Paper read before the American Iron and Steel Institute, May 25, 1928: *Iron Age*, 1928, Vol. 121, May 31, pp. 1529-1532). The paper opens with a brief outline of the basic open-hearth process, and proceeds to review the present position of the process, giving statistics of the production of different countries. The reasons for the growth of the basic process, particularly in the United States, are considered, and brief mention is made of the increase in size of furnaces. Attention is also drawn to the great variety and kind of steels made by the basic process. The methods by which the supremacy of the process may be maintained are discussed, and it is pointed out that the tilting furnace has not received sufficient consideration. Notwithstanding the increased cost of furnace and plant, it is believed that the tilting furnace affords advantages that offset the increased cost. One of the main ways in which the supremacy of the basic process will be maintained will be by a further study of the reactions that take place in steel-making, the reactions in the slag and the interactions between slag and metal. The importance of the slags in steel-making processes is not yet fully recognised, and before many years, it is believed, regular tests will be taken of the slag during the working of the heat, and analysed in similar ways

to the steel samples. To produce a sounder steel many experiments are still being made in methods of pouring, and the method used by the Ford Motor Co. is described in detail. The paper includes statistics relating to the production of steel ingots and castings in the United States, Great Britain, Germany, and France for the period 1900-1926.

A One-Ton Acid Open-Hearth and Some Experimental Results. C. E. Meissner. (American Institute of Mining and Metallurgical Engineers, 1928, Technical Publication No. 106; Iron Age, 1928, Vol. 121, Mar. 15, pp. 731-732). An account is given of acid open-hearth practice for the production of alloy steels. The design and construction of the furnace is described and illustrated. Two typical heats are shown on accompanying heat records giving details of alloy additions, slag working, analysis of metal, and similar details. One is a high carbon-chrome-molybdenum steel and the other a medium carbon steel with 3.5 per cent. of chromium. The furnace is oil-fired, using light, low-sulphur oil. All the alloying metals are added in the furnace except ferro-manganese, which is sometimes added in the ladle. The results obtained with this furnace may be duplicated on large-scale operation.

Notes on Open-Hearth Furnaces. M. J. Conway. (Blast-Furnace and Steel Plant, 1928, Vol. 16, Jan., pp. 18-19, 30). Consideration is given to furnace operation, with particular emphasis on the importance of training the furnace hands.

Practice in Making Open-Hearth Steel. C. W. Veach. (Blast-Furnace and Steel Plant, 1928, Vol. 16, Feb., pp. 258-259). The proportion of pig iron in the charge and the effects of iron oxide, manganese, and silicon are briefly discussed.

A Year's Progress in Open-Hearth Metallurgy. C. H. Herty, jun. (Fuels and Furnaces, 1928, Vol. 6, Jan., pp. 69-72, 80). The author reviews the advancement made in open-hearth practice in America, and discusses progress in research, furnace charges, furnace reactions, fuels and heat recovery, furnace construction, and accessories. A subject of considerable interest at the present time is the use of recuperators to take the place of part of the regenerative system. One important step in furnace design has been the construction and operation of the 250-ton stationary furnace of the Weirton Steel Co. These furnaces are apparently as easy to handle as small furnaces, and evidently the limiting size of stationary furnaces has not been reached.

Effect on the Economy of Open-Hearth Working of Varying the Proportion of Scrap and Pig Iron. G. Bulle. (Stahl und Eisen, 1928, Vol. 48, Mar. 15, pp. 329-338; Mar. 22, pp. 368-370). Some results are published of an inquiry addressed to several large steelworks on

the effect on output, quality of product, and losses in the furnace, of using light scrap or heavy scrap, a larger or smaller proportion of pig iron in liquid or solid form, and different grades of pig. The average results of a large number of trials are combined in an interesting diagram, which shows the variations in the following data, due to use of heavy rolling-mill scrap, light scrap, turnings and cast iron, or bundled scrap. The data for which the variations are shown are: the consumption of lime or dolomite per ton of steel, the fuel consumption in millions of cal. per ton of steel, the time in minutes per ton of steel, the ratio of yield to charge, the losses per cent. of the charge, the metallic manganese in kg. per ton of steel, and the pig iron in kg. per ton of steel. In general, the consumption of pig iron, manganese, fuel, and lime is increased by changing over from heavy forge and mill scrap to light scrap. The losses by burning and the period of the heat are likewise increased. The general view is confirmed that the use of liquid pig reduces the time and the consumption of manganese and fuel, but in one steelworks these advantages appear to be balanced by higher losses and increased cost of furnace repairs when using liquid pig. At another works, a higher proportion of metal was retained in the slag when liquid pig was used. Observations on the lines followed should, however, be greatly extended before the effect on output, quality, and costs of varying proportions of scrap and pig can be accurately judged.

The Application of Theoretical Chemistry to Some Important Operations in Steel Production. H. Schenck. (*Archiv für das Eisenhüttenwesen*, 1927, Vol. 1, pp. 483-495; *Stahl und Eisen*, 1928, Vol. 48, Feb. 16, pp. 199-201). The author gives expression, by means of chemical formulæ, to the principal reactions leading to a state of equilibrium in the steel bath. For complete removal of all oxides from the bath there is one means, namely, deoxidation with carbon under vacuum or under a neutral gas-phase. Otherwise the conditions for a high degree of deoxidation are summed up as follows: The deoxidation effect is greater, the greater the difference of the affinities for oxygen of the iron and deoxidising agent; the greater the capacity of the separated products of deoxidation to dissolve or chemically bind the residual iron oxide; and the lower the solubility of the deoxidation products in the metal. Since deoxidation is an exothermic reaction, the degree of deoxidation is greater the lower the temperature at which it starts.

The Heat Evolutions of Metallurgical Reactions. C. Schwarz. (*Archiv für das Eisenhüttenwesen*, 1928, Vol. 1, Feb., pp. 525-526). Since the appearance of the supplementary volume of Landolt and Börnstein's "Physical-Chemical Tables," it is evident that a number of the values, hitherto in general acceptance, for the heat evolutions of metallurgical reactions require correction. Some 70 reactions, of

some importance in the open-hearth process, are tabulated, showing the ratios of the molecular weights of the various elements and the heats of reaction in kg. cal.

Effect of Temperature on the Solubility of Iron Oxide in Iron. C. H. Herty, jun., and J. M. Gaines, jun. (American Institute of Mining and Metallurgical Engineers, 1928, Technical Publication No. 88). The solubility curve for FeO in pure iron was determined between the temperatures 1535° and 1750° C. Slags ranging from 40 mol per cent. FeO up to nearly pure FeO were employed, the diluent constituents being chiefly CaO and MgO. The solubility at 1535° C. is 0.94 per cent. FeO (0.21 per cent. O₂); at 1600° C. 1.36 per cent. FeO (0.304 per cent. O₂); and at 1700° C. 2.02 per cent. FeO (0.452 per cent. O₂). It is shown that FeO in the slag dissolves in iron as the compound FeO. It is also established that if any compounds are formed between lime and oxides of iron in the slag, these are broken up at the slag-metal surface so that all of the FeO is free to dissolve in the iron.

Rate of Carbon Elimination and Degree of Oxidation of the Metal Bath in Basic Open-Hearth Practice. A. L. Feild. (American Institute of Mining and Metallurgical Engineers, 1928, Technical Publication No. 111). The rate of elimination of carbon largely controls the time required to make a heat of steel by the basic process and to an important degree determines the cost of refining. Slags high in FeO which cause rapid carbon elimination seem to cause low quality in the final product, and a balance must be struck between the rate of carbon drop which would yield the best steel and that which would give the lowest cost. The paper is devoted to the development of certain equations derived from the established laws of physical chemistry which will enable this relation between rate of refining and the degree of oxidation to be computed from operation data. Attention is mainly confined to carbon elimination, but the application of the equations may readily be extended. It is concluded that there is no conflict between theory and practice, but it is only by a perfectly elaborated theory of the process that metallurgical and economic factors involved can be brought within intelligent understanding.

Theoretical and Experimental Investigations on the Deoxidation of Iron with Manganese. H. Schenck. (Stahl und Eisen, 1928, Vol. 48, Mar. 29, pp. 407-408). In a previous investigation by Oberhoffer and Schenck (*see* Journ. I. and S.I., 1927, No. II. p. 549), the equilibrium constants were calculated for the reaction $\text{FeO} + \text{Mn} = \text{MnO} + \text{Fe}$, with the aid of H. Styri's equation. Due to an arithmetical mistake having occurred in those calculations, the data have now been entirely recalculated.

Deoxidation of Iron with Manganese. J. M. Gaines, jun. (Blast-Furnace and Steel Plant, 1928, Vol. 16, Apr., pp. 479-481, 488). This

contribution is based on the original paper by Oberhoffer and Schenck, and includes comments by the translator.

The Melting or Molten Stage of Steel Manufacture, with Particular Reference to the Deoxidising, Refining, and Contamination Phases. G. A. Dornin. (Transactions of the American Society for Steel Treating, 1928, Vol. 13, Jan., pp. 29-48). The author mentions briefly the various steel-melting processes, and shows their possibilities in the making of clean steel. The extremely bad effect of oxides in steel is pointed out and the author considers that the best method of de-oxidising a bath of steel is by the introduction of silicon. The various steel-making processes according to their ability to make sound steel are placed in the following order: (1) crucible; (2) open-hearth; (3) Bessemer converter. The author considers the electric furnace a special form of open-hearth, instead of a distinctive process.

The Manufacture of Alloy Steel. E. C. Smith. (Paper read before the American Iron and Steel Institute, May 1928: Iron Age, 1928, Vol. 121, May 31, pp. 1532, 1578). The author discusses in a broad sense the present status of the manufacture of alloy steel.

A Brief Review of Electric Iron and Steel Furnace Practice during 1927. W. E. Lewis. (Iron and Steel Engineer, 1928, Vol. 5, Jan., pp. 7-8).

The Charge in Electric Furnace Operation. K. von Kerpely. (Die Giesserei, 1928, Vol. 15, Mar. 9, pp. 225-229). The author discusses the condition of scrap for use in the electric furnace, and indicates the influence of its quality on the amount of current used. The disturbance of the melting process through the use of unsuitable charges is also dealt with.

The Energy Losses in Electric Arc Steel Furnaces. S. Kriz. (Archiv für das Eisenhüttenwesen, 1927, Vol. 1, Dec., pp. 413-419). A determination is made of the magnitude of the total losses of energy in electric arc furnaces of the following types: (1) A single phase 5-ton Héroult furnace, basic lined, with 660 kva. transformer; (2) 3-phase 5½-ton Héroult furnace, basic lined, with 1500 kva. transformer; (3) three 3-phase 7-ton furnaces of the same description with 2000 kva. transformers; (4) one 5-ton, one 6-ton, and one 9-ton 3-phase Natusius furnaces, basic lined, with 1150 and 1500 kva. transformers. The average results, taken on 1000 heats of a 5-ton furnace, show for the melting down period a total consumption per heat of 885 kw. and an efficiency of 60·5 per cent. For the refining period the total consumption of energy is 542 kw. and an efficiency of 36·6 per cent. The proportionate energy losses in the refining period, mainly due to the greater heat radiation, appear therefore to be nearly double those of the melting-down period.

The Operation and Control of Electric Furnaces Studied by means of the Diagram. P. Bergeon. (*Revue de Métallurgie, Mémoires*, 1927, Vol. 24, Nov., pp. 683-694). A diagram and formulæ are put forward by which it is possible to study the electrical aspect of the operation of an electric furnace, and to determine the influence of the transformer on the power factor and the effect produced by a variation of the electrical tension. A new method of controlling furnaces is described in which the power factor is kept constant by manipulating the electrodes. This method is advantageous when the primary potential is variable and when the furnace has a relatively great inductance; the efficiency is increased and the furnace works more regularly.

British Electric Furnace Practice. H. C. Dews. (*Electrical Times*, 1927, Vol. 72, Oct. 6, pp. 416-419).

Some Points about Electric Metal Melting. V. Stobie. (Paper read before the Institute of British Foundrymen: *Foundry Trade Journal*, 1928, Vol. 38, Jan. 12, pp. 23-24). The author discusses the following features in connection with electric furnace melting: arc temperature and quality, the melting process, refining conditions, and viscosity of electric steel.

Principles Involved in Electric Heating. N. R. Stansel. (*Heat Treating and Forging*, 1928, Vol. 14, Mar., pp. 311-314). Apparatus and methods used to convert electricity into heat are described, and the principles of heat transfer, conduction, convection, and radiation are discussed.

The Present State of Development of the Induction Furnace. P. Bunet. (*Chimie et Industrie*, 1927, Vol. 18, Nov., pp. 751-757). The author deals with the electrical side of the development of induction furnaces.

Note on the Metallurgy of the High-Frequency Furnace. F. Wever and G. Hindrichs. (*Archiv für das Eisenhüttenwesen*, 1927, Vol. 1, Nov., pp. 345-355; *Stahl und Eisen*, 1928, Vol. 48, Jan. 5, pp. 11-13: *abstract*, *Metallurgist*, 1928, Jan. 27, pp. 6-7). A series of tests with a 50-kg. acid-lined 30-kw. high-frequency furnace has been carried out at the Iron Research Institute, and the operations involved in melting and refining low-carbon steels, chromium steels, high-carbon steels, and ball-bearing steels are described. The low-carbon and chromium steels (Cr = 13.05 per cent.) were put to severe tests by rolling and cold-drawing into tubes, and notwithstanding the heavy reductions in the passes not a single failure of a specimen was recorded. The high-carbon steels were tested by the repeated hardening method and gave quite good results. A further set of trials were made with a 100-kw. high-frequency basic lined furnace with charges up to 200 kg.

The materials produced were high-carbon steels, transformer steel, high-speed steel, and magnet steel, all of which proved to be of highest quality. With the 30-kw. furnace the energy consumption was 1265 kw.-hrs. per ton when melting cold steel scrap, and in the 100-kw. basic furnace the energy consumption was 880 kw.-hrs. with a charge of cold scrap.

Steels Made under New Conditions. (Iron Age, 1928, Vol. 121, Apr. 19, pp. 1073-1075). An abridged translation of a paper by F. Wever and H. Neuhauss dealing with the production of steel in high-frequency induction furnaces, which appeared in *Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung*, 1926, Vol. 8, pp. 171-179).

Tool Steel Manufacture. (Colliery Engineering, 1928, Vol. 5, Jan., pp. 21-23). A brief account is given of the refining of steel in an Ajax Northrup high-frequency furnace as carried out at the works of Edgar Allen & Co., Ltd., Sheffield.

A New Electric Steel Furnace. (Electrical Review, 1927, Vol. 101, Dec. 16, pp. 1029-1031). **Electric Crucible Steel.** (Machinery, 1927, Vol. 31, Dec. 15, p. 375). An illustrated description of an Ajax-Northrup high-frequency electric furnace.

The New Miguet Electric Furnace with Continuous Electrode. R. Sevin. (Journal du Four Electrique, 1927, Vol. 36, Nov. 15, pp. 245-247). Particulars are given of the furnace installed at Montricher, and its method of operation is described.

SLAGS.

Some Constituents of Basic Open-Hearth Slag. J. M. Ferguson. (Royal Technical College Metallurgical Club Journal, 1927-28, No. 6, pp. 9-18). A short account is given of the constituents isolated from basic finishing slags, together with a consideration of some aspects of their occurrence therein. The slag minerals described were chemically analysed, examined in reflected and oblique light, and observations made of their optical behaviour in thin sections by means of polarised light.

Lime in Metallurgical Slags: Being a Contribution to the Problem of Slag Reactions. H. Fliegenschmidt. (Thesis presented to the Technical High School at Breslau, 1927, pp. 1-16). A discussion of the part played by lime in the constitution of metallurgical slags.

A Further Contribution to the Study of the Citric Acid Solubility of Phosphoric Acid in Basic Slag. A. Süllwald. (*Archiv für das Eisenhüttenwesen*, 1928, Vol. 1, Mar., pp. 565-568). The investigation was directed to ascertain the changes in citric acid solubility of the phosphoric slag in transit from the converter to the storage place. Segregation phenomena in the liquid basic slag and the influence on the citric solubility of sudden cooling on the one hand, and of heating to incandescence on the other, were studied.

STEEL PLANTS.

New Plant of the Appleby Iron Co., Ltd. A. Crooke and T. Thomson. (Paper read before the Iron and Steel Institute, Annual Meeting, May, 1928; this Journal, p. 171).

Extensions of the Appleby Iron Company. (*Iron and Coal Trades Review*, 1928, Vol. 116, Mar. 2, pp. 287-290).

The Reorganisation of Crewe Locomotive Works. H. P. M. Beames. (Paper read before the Institution of Mechanical Engineers, Mar. 16, 1928: *Engineering*, 1928, Vol. 125, Mar. 23, pp. 362-366; *Engineer*, 1928, Vol. 145, Mar. 23, pp. 314-318). The layout and equipment of these works are described and illustrated in full. The new steel-making plant consists of two 40-45 ton acid open-hearth furnaces and two 60-70 ton basic open-hearth furnaces, with an estimated yearly output of 84,840 tons of ingots. The gas and air out-takes from the slag chambers are built up separately with air circulation all round, thus preventing the possibility of mixing and consequent destruction of the brickwork. The furnace hearth is carried quite clear and independently of the slag pocket area, and the entire hearth and port ends are joined up in a strong independent framework carried on the furnace bottom joists. The hearth of the acid furnace at fore-plate level is 11 ft. wide by 28 ft. long, giving an area of 308 sq. ft., or 7.7 sq. ft. per ton of furnace capacity. The hearth of the basic furnace at fore-plate level is 14 ft. wide by 36 ft. long, giving an area of 504 sq. ft. or 8.4 sq. ft. per ton of furnace capacity. The regenerators are capacious; in the acid furnace they contain 10.1 cu. ft. per sq. ft. of hearth area, and in the basic furnace 10.7 cu. ft. per sq. ft. of hearth area. Six mechanical gas machines are in use designed to gasify all the coal required to operate the melting furnaces and to supply the forge and rolling mills and the reheating furnaces.

The Works of William Beardmore & Co., Mossend Steelworks. (*Foundry Trade Journal*, 1927, Vol. 37, Oct. 27, pp. 61-62). An illustrated account is given of the equipment of this plant.

Famous British Works. (Iron and Steel Industry, 1927, Vol. 1, Dec., pp. 77-82; 1928, Vol. 1, Feb., pp. 141-145; April, pp. 215-218). The continuation of a series of descriptive illustrated articles (see Journ. I. and S.I., 1927, No. II. p. 556). In the present numbers are described the works of Messrs. Leys Malleable Castings Co., Ltd., the Cargo Fleet Iron Co., Ltd., and the Wigan Coal and Iron Co., Ltd.

What the Eyes Behold at Sydney Steel Plant. W. S. Wilson and A. P. Theurkauf. (Iron and Steel of Canada, 1927, Vol. 10, Nov., pp. 331-341). An illustrated description of the iron and steel works and coke-oven plant of the Dominion Iron and Steel Co., Ltd., at Sydney, Nova Scotia.

Employs Unique Methods in Making Basic Steel. J. D. Knox. (Iron Trade Review, 1927, Vol. 81, Dec. 29, pp. 1603-1606). An account of steel-making practice at the Fordson plant of the Ford Motor Co. There are seven 100-ton basic furnaces, four of the tilting type and three of the stationary type. The furnaces are fired with tar and are fitted with waste-heat boilers. Ingots are poured four at a time into oval-shaped moulds fluted on the interior. The moulds measure 12 in. on the long diameter of the oval, 10 in. on the short diameter, and are 60 in. long. Approximately 120 moulds are required to handle a heat of steel. The ingots are bottom-poured and hot tops are used.

Manufacture of Steel for the New Ford. J. B. Nealey. (Blast-Furnace and Steel Plant, 1928, Vol. 16, Apr., pp. 487-488). An outline is given of open-hearth furnace practice at the Fordson plant of the Ford Motor Co.

Gas Fuel Used in Making the New Ford. J. B. Nealey. (Heat Treating and Forging, 1928, Vol. 14, Feb., pp. 187-189; Mar., pp. 307-309).

STEELWORKS MACHINERY.

Steelworks Machinery. J. Foster-Smith. (Transactions of the Manchester Association of Engineers, 1926-27, pp. 25-46). The author reviews the various forms of material-handling apparatus used throughout the modern steelworks.

Air Compressor Coupled to a Steelworks Blower. K. Linck. (Revue Technique Luxembourgeoise, 1928, Vol. 20, No. 1, pp. 7-8). A brief description of an air compressor which has been coupled to the blower in the Burbacher Hütte Steelworks is given, together with some details of its performance in use.

Fifteen-Ton Electro-Hydraulic Casting Crane. (Engineer, 1928, Vol. 145, Mar. 2, pp. 244-246). A detailed illustrated account is given of a modern type of ingot-casting crane manufactured by the Ateliers de Constructions Electriques de Charleroi. The crane in question comprises a motor-driven travelling carriage, from the centre of which rises a vertical pivot which acts as the fixed ram of a hydraulic cylinder. This cylinder, which surrounds the ram, carries the main portion of the crane. On one side there are extensions in the form of two arms to carry the ladle between them. The latter can be traversed along the arms through a range of about 3 ft. inwards from its extreme position, which is at nearly 15-ft. radius from the centre of the pivot. On the opposite side the structure is extended to support a platform on which are situated the pumps and operating mechanism, the whole being enclosed in a cabin and serving to counterbalance the weight of the ladle.

CASTING AND TREATMENT OF INGOTS.

Second Report on the Heterogeneity of Steel Ingots. (Iron and Steel Institute, Annual Meeting, May, 1928; this Journal, p. 401).

The Use of Metallography in Improving the Quality of the Product. H. Meyer. (Stahl und Eisen, 1928, Vol. 48, Apr. 19, pp. 506-515). The author discusses means for discovering the amount and distribution of the segregation in ingots of killed and unkilld steels, macrographs of such ingots being given to show the structure of the steel, killed and unkilld, and of steel compressed by the Harmet process. A series of 5-ton mild steel ingots was examined with the object of disclosing the range of segregation of sulphur, phosphorus, and carbon. The analysis showing the general composition of the ingots is not stated, but the following table shows the variation from the average in the three elements mentioned, the samples being taken at eight points along the vertical axis of the ingot :

	Sulphur. %		Phosphorus. %		Carbon. %	
	Unkilled.	Killed.	Unkilled.	Killed.	Unkilled.	Killed.
1 (bottom)	— 45	— 27	— 25	— 14	— 40	— 14
2	+ 50	— 9	+ 20	— 6	— 17	— 11
3	+ 70	+ 23	+ 40	+ 7	+ 8	— 6
4	+ 130	+ 32	+ 90	+ 11	+ 33	+ 3
5	+ 205	+ 46	+ 120	+ 16	+ 72	+ 7
6	+ 315	+ 55	+ 150	+ 28	+ 125	+ 13
7	+ 375	+ 68	+ 200	+ 36	+ 150	+ 20
8 (head)	+ 600	...	+ 360	...	+ 210	...

In an unkilld steel ingot compressed by the Harmet process, the variation of the carbon from the mean carbon content is shown to be from -18 to $+150$ per cent., that of phosphorus from -8 to $+180$ per cent., and that of sulphur from -19 to $+250$ per cent. in different zones of the ingot.

Negative, or Inverse, Segregation, and White Spot. L. Pichard. (*Génie Civil*, 1928, Vol. 92, Feb. 11, pp. 132-134). The author describes the process of cooling of an ingot, the phenomenon of inverse segregation and the occurrence of the "white spot" in bars made from it. The graduation of the colours produced by etching sections of the ingot by means of iodine can be used to indicate the presence of these two phenomena.

The Central White Spot in Steel Ingots Rolled before Complete Solidification. — Viteaux. (*Génie Civil*, 1928, Vol. 92, Apr. 7, pp. 333-335). The author criticises the explanation of the presence of the white spot in material rolled from ingots before complete solidification, given in the preceding article. He points out that the appearance of the white spot is always accompanied by very marked heterogeneity, which is manifested not only in the variations of the contents of sulphur and phosphorus, but, what is of capital importance, by the variation in carbon contents. He reproduces the section of an ingot intentionally rolled before the interior had completely solidified and tabulates the analytical results obtained at points ranging from the outside to the centre. The outside material analysed as follows: Carbon 0.412, manganese 1.000, phosphorus 0.075, sulphur 0.038 per cent. The next layer contained slightly more of each element, but the succeeding layers contained progressively less of each element until the central portion contained carbon 0.132, manganese 0.910, phosphorus 0.023, sulphur 0.009 per cent. The author's opinion is that it appears very difficult to admit that liquation alone, accompanied by an under-cooling phenomenon, necessarily followed by a rapid solidification, should be able to reproduce the considerable impoverishment in carbon, phosphorus, and sulphur revealed by the analyses. The author reviews the suggestions put forward by one or two other workers to explain the phenomena observed, and considers that the explanation of Hobaer, based on the known laws of the solidification of binary alloys, fits the known facts best. He discusses this explanation in considerable detail. The author refers to the First Report of the Heterogeneity Committee of the Iron and Steel Institute, and suggests that the explanation which he gives should be capable of throwing some light on some of the anomalies noted by that Committee.

Causes of Bloom Croppage Losses. G. D. Johnson. (*Blast-Furnace and Steel Plant*, 1928, Vol. 16, Mar., pp. 381-384). A discussion of the origin of defects in steel ingots.

Casting Temperature of Steel and Speed of Pouring. F. Beitter. (Stahl und Eisen, 1928, Vol. 48, May 3, pp. 577-583). The casting temperature of steel depends mainly upon the chemical composition in view of the fact that the freezing point is generally lowered and the fluidity is affected in proportion as the weight and number of the alloying elements is increased. The melting temperature of ordinary carbon steels ranges between 1350° and 1520° C., and the most difficult operation in steel melting is to determine within 10° or 20° the temperature of the bath underneath the slag blanket. It might be measured pyrometrically by thrusting into it a close-ended graphite tube, but this method is both costly and troublesome. The accuracy of optical measurements cannot be relied on as they may vary within wide limits on account of radiation, fumes, and oxide films. The simplest and safest method is the observation of ladle samples; the degree of superheat of the steel can be readily judged by taking a sample of the bath, skimming off the slag, and noting the time taken for a film to form on the surface of the sample. After tapping a 50-ton furnace the liquid steel can cool for 15 minutes in the ladle without risk of the stopper getting stuck in the nozzle, and if well covered with slag there will then be very little further loss of temperature in the whole charge from the time of starting to pour till the last mould is filled. The speed of pouring stands in close relation to the temperature, and the ladle should be so designed as to reduce as far as possible the variation of speed due to the diminishing depth of the molten metal in the ladle. Curves are plotted showing the diminishing speed of flow from a 50-ton ladle, the maximum depth of the bath at the start being 2.6 m., and the corresponding diminution in kg. of metal per sec. as pouring proceeds. In order that the speed at which the stream of metal enters shall be kept constant, a dish of special refractory material may be placed on the top of each mould. The bottom of the dish is provided with about six holes, so that the stream coming from the ladle into the dish is checked and broken up into smaller streams and the metal then enters the mould at an even speed and with much reduced splashing. It is a curious phenomenon that the crust which forms in the top of the liquid steel in the mould if quiet floats on the surface, notwithstanding that it is of higher specific gravity than the steel. This can only be accounted for as being due to surface tension, which, as is well known, is high in the case of liquid metals. If anything occurs to disturb the equilibrium while the metal is still liquid, the crust sinks at once and forms slag enclosures in the ingot.

Ingot Teeming Speed and Quality. E. G. Smith. (Iron Age, 1927, Vol. 120, Dec. 22, p. 1725). A very brief discussion of a number of factors which influence the rates of teeming. According to the author, for "dead killed" steels made in an acid open-hearth furnace, a clay nozzle gives more regular teeming speeds from one end of the cast to the other, since the wearing of the nozzle compensates for the loss of

pressure in the ladle. For basic steel teeming, magnesite nozzles are recommended.

The Technical Casting of Certain Steel Ingots. E. Lubojatzky. (Montanistische Rundschau, 1928, Vol. 20, Jan. 1, pp. 1-8; Jan. 16, pp. 27-34). The chemical and physical properties of certain silicon, manganese, chromium, tungsten, and nickel steels are described, and their behaviour during solidification and cooling in the mould is discussed. Errors of casting and their prevention are also dealt with.

The Cascade Method of Pouring Steel. J. G. Morrow. (Transactions of the Canadian Institute, 1927, Vol. 30, pp. 828-838). The author gives a brief description of the cascade method in use at the open-hearth plant of the Steel Co. of Canada for the pouring of ingots. The steel is poured from a ladle through a trough or box into moulds stepped one below another. The moulds are so connected that the metal overflows from the highest mould into the next, and so on until the last mould is filled. It is claimed that steel poured in this manner shows less piping, segregation, &c., and gives a higher yield.

Influence of Heating Prior to Rolling of Soft Steel Ingots on Structure and Strength of the Material. H. Bitter. (Archiv für das Eisenhüttenwesen, 1927, Vol. 1, pp. 371-378; *abstract*, Stahl und Eisen, 1928, Vol. 48, Jan. 12, pp. 38-39). The problem was to discover whether by allowing the ingot to cool after teeming and then reheating and rolling, any improvement resulted in the mechanical properties of the material. Only one class of steel was used for the experiments—viz. a cast steel with C 0.09, Si 0.0, Mn 0.53, P 0.055, and S 0.035 per cent. Two ingots were taken for each test. One pair was rolled direct at an initial temperature of 1190° C. and 1180° C. respectively. The other pair was allowed to cool, was then reheated and rolled at 1160° C. and 1060° C. In all four cases the billets were rolled to $4\frac{3}{4}$ in. square. Analysis showed that segregation was highest in the billets rolled direct without reheating, the elements being found most strongly segregated, as one might expect, in that part representing the ingot head; in other words, it is claimed that reheating an ingot modifies the extent of segregation. In general, quick cooling and reheating refines the grain structure. Specimens taken from the head, centre, and foot of the billets were subjected to hardness, tensile, and impact tests. The two former kinds of test revealed no difference, but the impact tests on the specimens from the cooled and reheated ingot gave distinctly better results than those from the ingot rolled direct, whether tested in the direction of rolling or transversely thereto.

Ingot Mould Life and Chemical Analysis. E. H. Williams. (Blast-Furnace and Steel Plant, 1928, Vol. 16, Jan., pp. 29-30). In order that an ingot mould may have a long life the chemical composition

of the iron used and the casting temperature must fall within specified limits. As a suitable composition is given: Si 1.75, S as low as possible, P about 0.10, and Mn 0.80 to 1.00 per cent. Mould failures and their causes are briefly discussed, and the cause of "fire-cracking" is ascribed to growth of the cast iron; reference is made to special mixtures designed to overcome this growth.

Relation of Mould Analysis to Mould Life. (Mining and Metallurgy, Feb. 1928, pp. 64-66). An account is given of a discussion which took place at the Open-hearth Conference held at Detroit on Nov. 3, 1927. The principal factors influencing the life of ingot moulds were dealt with.

Ingot Moulds and their Design. C. Gejrot. (Jernkontorets Annaler, 1927, Vol. 111, pp. 121-242; Stahl und Eisen, 1928, Vol. 48, Jan. 19, pp. 77-78). The first part of this work consists of a reproduction of the data presented in the Report of the Iron and Steel Institute Committee on Heterogeneity of Steel Ingots (Journal No. I., 1926), where the freezing conditions of large ingots were under investigation. The author then proceeds to relate his own investigations on freezing conditions in small ingots, which, in essentials, resemble those of large ones. In a discussion of ingot mould design, it is maintained that the taper of the ingot is a much more important factor than the thickness of the wall of the mould in influencing soundness and segregation. For ordinary ingots a taper of 40 mm. in 1 m. (say, $1\frac{1}{2}$ in. in 3 ft.) is necessary. For hard steel a greater taper is recommended. In Swedish steel practice the thickness of wall at top of the chill averages 2 in. for 8-in. ingots, 3 to $3\frac{1}{4}$ in. for 12-in. ingots, and $4\frac{1}{2}$ to 5 in. for 14- to 15-in. ingots. The size of ingot commonly used in Sweden for tool steel is 8 to 10 in., and opinions differ as to whether a square section or a six-, eight-, or twelve-sided section is best. In ingots of square section, a radius of $1\frac{3}{4}$ to 2 in. is suitable for the corners. The weight of the feeder head is 10 to 18 per cent. of the total ingot. For large moulds, the composition of the cast iron recommended is 1.8 per cent. Si, and 0.8 per cent. Mn; for small moulds, 1.0 per cent. Si, and 1.0 per cent. Mn. The life of such moulds is 40 to 60 casts for hard steel, and 90 to 110 for soft steel. At Bofors, steel moulds with 0.22 to 0.25 per cent. C are used with good results, the life being 300 casts, but the cost of a steel mould is about three times that of a cast-iron one. A number of notes on surface defects of ingots and their avoidance are given.

Trend in Ingot Mould Design. R. H. Watson. (Paper read before the American Iron and Steel Institute, May 1928: Iron Age, 1928, Vol. 121, May 31, pp. 1579-1580). The paper opens with a discussion of the influence of taper on the freezing of metal in moulds, and it is pointed out that the necessity of any taper whatever is questionable. The desirable requirements of hot tops are enumerated, and several

types and sections of moulds in general use are illustrated. A number of charts are included showing cooling effects of varying wall thicknesses in moulds, and segregation in ingots poured in moulds of varying sections and differing wall thicknesses. Attention is also paid to the question of corner radius of the ingot, and mention is made of a rule adopted at Bethlehem for rectangular moulds, to make the corner radius equal 13 per cent. of the longest side, and for large moulds somewhat less. The use of dished stools is said to result in a lighter bottom crop and to lessen the likelihood of butt cracks. The tendency in the shape of the ingots is to abandon the straight-sided ingot, and recent designs are bulged or concave, corrugated or fluted. One of the most successful ingots used is the twelve-sided fluted ingot, which has the advantage of the yielding periphery, and if the quick cooling saliences do nothing more, they limit the length of horizontal cracks.

Water-Cooled Copper Moulds. W. Rohn. (Zeitschrift für Metallkunde, 1927, Vol. 19, Dec., pp. 473-478). Experiments carried out to determine the best form of water-cooled copper moulds into which metals, melted under a vacuum, could be cast *in vacuo* are described. The importance of the relationship between the heat conductivity of the mould metal and the resistance to transfer of heat from the outside of the mould wall to the cooling water was demonstrated. Hollow-walled moulds were prepared with spiral fins arranged in the annular space. If the fin were attached to the outer wall, leaving a minute water space between the inner edge of the spiral and the inner wall, then the latter burnt through opposite the fin; if, on the other hand, the spiral fin formed an integral part of the inner wall, burning through did not occur opposite the fins, as the heat was able to flow through the mould into the fins, whence it reached the water by way of the sides of the fins.

FORGING AND ROLLING-MILL PRACTICE.

REHEATING FURNACES.

Reheating Furnaces Fired with Blast-Furnace Gas. J. Meiser. (Archiv für das Eisenhüttenwesen, 1928, Vol. 1, Apr., pp. 639-646). The author gives a well-illustrated description of continuous horizontal reheating furnaces and soaking pits fired by blast-furnace gas as installed at the works of the Dortmunder Union, showing dimensions and structural details. In a battery of soaking pits the average daily throughput is 430 to 450 tons of ingots with a gas consumption of 240 cu. m. per ton of a calorific value of 1000 kg. cal. per cu. m., equivalent to a coal consumption of 3.4 per cent. A new continuous furnace in connection with a universal mill takes 535 cu. m. of gas per ton of steel, the hearth temperature being 1330° C., and the billets are charged at an initial temperature of 100° to 600° C.

Town-Gas-Fired Plate and Bar Reheating Furnace. (Iron and Coal Trades Review, 1928, Vol. 116, Mar. 16, p. 386). Particulars are given of the furnace in operation at the Bullring Dock of Smiths Dock Co., Ltd. Although provision is made for using the full length of the furnace chamber when required, under normal conditions it is worked as a plate and bar furnace arranged in tandem, and controlled independently. The plate end of the furnace is 31 ft. long \times 10 ft. wide \times 4 ft. high, and the bar end 27 ft. long \times 4 ft. wide \times 3 ft. 3 in. high. The furnace is of the recuperative regenerative type. Gas is supplied from a gas-reversing valve through mains extending along both sides of the furnace, the mains being fitted with adjustable gas jets which enter the furnace through ports, of which there are eight on the plate and seven on the bar end of the furnace. Starting from cold a temperature of 1150° C. can be attained within the furnace in a period of 2 hrs. In actual operation it has been found that the gas consumption at the plate end is approximately 8000 cu. ft., and that at the bar end 5000 cu. ft. per hr.

Experimental Researches made on a Pusher Furnace of the Morgan Type. M. Steffes. (Revue Technique Luxembourgeoise, 1928, Vol. 20, No. 1, pp. 1-6). The furnace is of the continuous type, with a suspended roof and double regeneration on the Siemens system; it is heated by blast-furnace gas. The charging and discharging of the billets is carried out automatically either by pushers or else by electrically

operated rolls. The experiments included the determination of the output when charged cold and the gas consumption ; a thermal balance-sheet is produced.

Pulverised Coal-Fired Forge Furnaces. J. Isoré. (*Aciers Spéciaux*, 1928, Vol. 3, Feb., pp. 62-66). The operation of pulverised coal-fired forge furnaces is discussed, and different types of furnaces are briefly described. Their advantages are outlined.

Furnace Aids in Modernising Forgings. F. W. Manker. (Forging, Stamping, Heat Treating, 1927, Vol. 13, Nov., pp. 431-432). **Modernising Forging Practice.** F. W. Manker. (*Iron Age*, 1928, Vol. 121, Feb. 9, pp. 401-404). The equipment for heating and handling forgings at the Willys-Overland Co.'s plant at Toledo, Ohio, is very briefly described.

Forging Methods and Heating to Forge. W. M. Hepburn. (*Heat Treating and Forging*, 1928, Vol. 14, Jan., pp. 41-43). The relation of proper heating to good results and certain types of forge furnaces are discussed.

Loss of Iron by Burning in Reheating Furnaces Fired with Coal-Dust. K. Rummel. (*Archiv für das Eisenhüttenwesen*, 1928, Vol. 1, Jan., pp. 499-504 ; *Stahl und Eisen*, 1928, Vol. 48, Jan. 26, pp. 102-103). This is a report on comparative trials with continuous reheating furnaces fired with coal-dust and with gas. The drawing temperature of the billets was 1250° to 1260° C. in one trial, and 1290° to 1300° C. in a second trial, both with coal-dust. In the trials on the gas-fired furnaces, a mixture of coke-oven gas and coal producer-gas was used, having a calorific value of 2100 kg. cals. per cu. m., the drawing temperature being 1225° C. In both cases the trials were made with the billets lying stationary and with the billets travelling. The results of the tests, which are very clearly shown in diagrams, indicate no appreciable difference in loss by burning, whether using coal-dust or gas.

Better Forgings Produced through Furnace Control. E. J. Edwards. (*Iron Age*, 1928, Vol. 121, Jan. 12, pp. 127-129). An illustrated account is given of the equipment of the new forge plant built by the American Locomotive Co. at its Brooks Works, Dunkirk, N.Y. Six heating furnaces are installed, which operate in two sets of three. The furnaces are of the regenerative type, and oil fired. In normal operation there are each morning two cool furnaces ready for charging, two hot furnaces containing steel ready for the press, and the remaining two cooling off. Two additional furnaces are installed for heating wrought-iron forgings. All large round work such as driving and trailing axles, as well as main crank pins, are forged under a 1000-ton steam-hydraulic press.

A 10,000-lb. manipulator moves and revolves the ingot or billet to the various positions required. An extensive heat-treating department is also installed.

Industrial Induction Furnaces. E. Russ. (Centralblatt der Hütten und Walzwerke, 1927, Vol. 31, Oct. 19, pp. 600-602). The Russ and Industrie types of reheating and muffle furnaces with induction heating are described.

FORGING, STAMPING, AND DRAWING.

Drop-Forging Industry and Equipment. M. S. Reed. (Heat Treating and Forging, 1928, Vol. 14, Jan., pp. 32-33, 40). The present status of the industry in America and improvements in methods and equipment to meet changed conditions, the four-roll drop-board hammer and speed and accuracy of hammer operation, are discussed.

The Drop-Forging Industry in Australia. G. W. Kemlo. (Drop Forger, 1928, Vol. 8, May, pp. 19-31). An account is given of the equipment of one of the leading drop-forging plants in Australia, and examples of the work produced are illustrated.

A Converted Drop-Hammer Plant. (Engineer, 1928, Vol. 145, Jan. 27, pp. 110-111). An illustrated description of the drop-hammer plant of the Westinghouse Brake and Saxby Signal Co., Ltd., at Chippenham, Wiltshire. Details are given of the friction-driven lifters and of the electric drives.

The "Eumeco" Drop-Hammer. R. W. Peck. (Drop Forger, 1928, Vol. 8, May, pp. 46-58). An illustrated account is given of the design of the "Eumeco" hammer, which is used to a large extent in Germany.

Forging Manufacture. J. Fearn. (Paper read before the Birmingham Branch of the Institution of Production Engineers, Feb. 29, 1928; American Machinist, European Edition, 1928, vol. 68, Mar. 3, pp. 41E-44E). The processes employed in making forgings are outlined and discussed.

Forging and Refining. L. Persoz. (Aciers Spéciaux, 1928, Vol. 3, Jan., pp. 3-12). The effect of forging on the mechanical and physical properties of high quality steels is discussed.

The Manufacture of Large Rounds by Forging or Rolling. J. Courthéoux. (Revue de Métallurgie, Memoires, 1928, Vol. 25, Feb.,

pp. 76-81). Former French railway specifications demanded that the first operation in producing wagon axles should be that of forging; rolling might be used only as a finishing operation. Later specifications reverse the order in which these operations shall be carried out. Experiments designed to compare the relative advantages of rolled bars and forged bars (160 mm. diam.), and the effect of annealing on these two types, are described. The author considers that the tests described demonstrate the superiority of the rolled material, provided that the raw material is of good quality.

A Note on the Preceding Article. E. de Loisy. (*Revue de Métallurgie, Mémoires*, 1928, Vol. 25, Feb., p. 81). The author describes the production of axles of basic open-hearth steel by rolling and turning, without any forging. The mechanical reception tests, which were largely met by the axles prepared in the manner described, are noted.

Charts for Determining the Heating Time of Forgings. H. Freund. (*Maschinenbau*, 1927, Vol. 6, Sept. 1, pp. 853-856).

Steels for Locomotive Forgings. E. J. Edwards. (*Iron Age*, 1928, Vol. 121, Jan. 26, pp. 255-258). The production and treatment of steel for locomotive forgings at the works of the American Locomotive Co., Schenectady, are described. Corrugated ingots of acid steel cast with hot tops to eliminate segregation and piping are used for the larger forgings. Ingots are charged into cold oil-fired furnaces and heated slowly to avoid internal ruptures and to ensure uniform penetration of the heat throughout the mass. Forging is done under a hydraulic press of 1000-ton capacity. Most of the driving rods, crank pins, and piston rods are made from alloy steel as well as straight carbon steel. The standard practice is to anneal and normalise both types of steel unless otherwise specified.

Locomotive Forging Steels. O. V. Greene. (*Transactions of the American Society for Steel Treating*, 1928, Vol. 13, Apr., pp. 573-602). The author gives the results of tests made on various types of heat-treated alloy steels for reciprocating locomotive parts. Many railroads in America are using simple alloy or carbon steels in the normalised condition for their forgings on account of the many difficulties encountered with complex steels and quenched and tempered carbon steels. In a normalised forging steel the internal fissures and cracks found in quenched material are never present. The magnitude of internal strains found in many of the quenched forgings is never encountered in normalised material, with the exception of the manganese forging steels, and well-defined ferrite segregation due to non-metallic impurities is also seldom found in normalised forgings. While the normalised carbon steel forgings do not show physical properties equal to the vanadium and manganese steels, their use is justified since they

may be economically and safely applied to all classes of locomotives if the sections are large enough to insure the necessary factor of safety.

Ford Blazes new Trail in Metal Working. E. C. Barringer. (Iron Trade Review, 1928, Vol. 82, Mar. 22, pp. 739-741, 754). **Ford Uses Forged Spun and Welded Parts for Axle Housings.** J. D. Knox. (Iron Trade Review, 1928, Vol. 82, Apr. 5, pp. 875-878). **Ford Spins Steel to Shape between Motor Driven Rollers.** J. D. Knox. (Iron Trade Review, 1928, Vol. 82, Apr. 12, pp. 933-936). **How Ford Stamps and Welds Parts for Fan and Gas Tank.** J. D. Knox. (Iron Trade Review, 1928, Vol. 82, Apr. 26, pp. 1059-1062). **Build Ford Ring Gear from Hot Rolled Special Shapes.** J. D. Knox. (Iron Trade Review, 1928, Vol. 82, May 3, pp. 1136-1139). A series of illustrated articles describing the stamping, forging, and welding processes employed by the Ford Motor Company in the production of the new type of Ford car.

Forging Machine Die Design for Deep Piercing. E. R. Frost. (Transactions of the American Society for Steel Treating, 1927, Vol. 12, Dec., pp. 954-967). The author describes the method and die design for producing upset machine forgings having deep holes pierced through them. The procedure to be followed in the design of the dies and piercers, as well as the pitfalls to be avoided, are described. The kind of material that can be forged, the working temperatures, and the kind of steel and treatment for piercer tools are dealt with.

Over-Heating and Burning during Stamping. (Drop-Forger, 1928, Vol. 8, May, pp. 59-68).

Wickes Forming Press for Boiler Shells. (American Machinist, European Edition, 1927, Vol. 67, Dec. 31, p. 833). The press has an open span of 30 ft. and can produce a pressure of about 3,000,000 lb. By means of a mandrel, 36 in. in diameter, cylinders of small diameters can be formed with only one longitudinal seam.

Formed Shells produced in Hydrostatic Dies. G. P. Anthes. (American Machinist, European Edition, 1928, Vol. 68, Mar. 10, pp. 207-209). Describes the drawing of a shell with an expanded portion at the closed end. The material was 0.062 in. dead soft, cold-rolled strip steel; five drawings were required and the expanded portion was "bulged" by means of oil under pressure.

The Plastic Behaviour of Metal in Drawing. C. L. Eksergian. (Transactions of the American Society of Mechanical Engineers, 1926, Vol. 48, pp. 609-642). A general discussion of the problems connected with plastic flow of metals in cold-drawing and stamping.

ROLLING-MILL PRACTICE.

Possibilities in Rehabilitation of Existing Rolling-Mill Equipment in British Steelworks. G. A. V. Russell. (Paper read before the Institution of Mechanical Engineers, Apr. 3: Iron and Coal Trades Review, 1928, Vol. 116, Apr. 20, pp. 555-557; May 4, pp. 665-668). British rolling-mill practice is reviewed in the light of some of the author's reflections on what might be achieved in lowering production costs through judicious rehabilitation of existing equipment. A chart is given showing the distribution of rolling costs in three typical works. A comparison is made of British and American practice and the possibilities of modernising the manufacturing equipment for semi-finished material are considered. Apart from a considerable strengthening up of the mill plant as a whole to enable heavy drafts to be taken with increased reliability and a much greater degree of refinement in mechanical design to reduce maintenance costs to a minimum, by far the greatest advances that have been made in blooming-mill design from the operating standpoint have been in the development of improved means for the manipulation of the piece at the rolls whereby the mill train and drive—the most costly part of the plant—can be more efficiently utilised.

The two chief ways of reducing production costs in many existing merchant-mill plants are by increasing the billet weights for the lighter products rolled, and eliminating some of the hand labour employed on the mill proper, and in finishing the products. Of great importance to the merchant mill is the mechanical cooling bed. The chief desiderata of a good mechanical cooling bed are: (1) The run-out table should act as a straightening device; (2) the piece, on being discharged on to the traversing mechanism, should be subjected to a further straightening action, and should be supported in such a fashion as to prevent warpage until it is sufficiently rigid; (3) the cooled bars should be assembled mechanically in an orderly manner upon the shear table; (4) to reduce power consumption and wear and tear the discharging device should be operated separately from the traversing mechanism; and (5) it is desirable to be able to pitch the bars out on the bed at intervals to suit their section.

To fully utilise the labour-saving possibilities of a mechanical cooling bed, efficient shearing, bundling, and weighing facilities should be provided.

The Practical Determination of the Power Requirements of Rolling-Mills. G. B. Lobkowitz. (Röhrenindustrie, 1928, Vol. 21, Jan. 5, pp. 5-7; Mar. 15, pp. 131-133). The author draws attention to the importance of the economy of power in rolling-mills and discusses the determinations of power requirements devised by Puppe, Mayer, and Kiesselbach. He points out the insufficiency of the determination of the "coefficient of squeezing." He then discusses the determination

of the power requirements by a combination of calculation and measurement, and describes the determination of the power requirements of a five-stand Morgan mill by this means.

Calculation of Roll Pressure and Power Requirements. S. Ekelund. (Jernkontorets Annaler, 1928, Vol. 83, pp. 67-100; *abstr.*, Röhren-industrie, 1928, Vol. 21, Apr. 12, pp. 171-173; Apr. 26, pp. 188-189).

Figuring Efficiency of Steel Mills. F. C. Smith. (Iron Age, 1927, Vol. 120, Dec. 29, pp. 1781, 1828). A method is put forward for calculating the true efficiency of rolling-mills, making allowances for lost time, cobbles, changing sections, &c.

The Rolling-Mill in 1927. B. R. Shover. (Iron and Steel Engineer, 1928, Vol. 5, Jan., pp. 4-6). A review of the improvements made in rolling-mill practice during 1927.

Housings with Exchangeable Roll Frames. L. Freilinghaus. (Iron and Coal Trades Review, 1928, Vol. 116, Jan. 13, pp. 47). Brief illustrated particulars are given of the Schloemann type of exchangeable roll frames for rolling-mills in which the rolls, chocks, yoke, guide, and guards are accommodated in a solid cast steel frame, which fits panel fashion into the housings. In changing over only the caps of the housing have to be removed, and in order that the spindles and sleeves need not be removed, these—if no spindle bearings are used—are supported by special devices, which can be carried out simply and expeditiously. In the case of three-high housings with exchangeable frames and electrical adjustment of the top and bottom rolls, the balancing of the top roll is effected by a counterweight, which is accommodated in the cross-piece connecting the two cap pieces and rests on levers having their fulcrum in the exchangeable frame and engaging in the chocks which they force upwards, so that contact between chocks, safety device, spindles, and adjusting nut is always assured.

Fuel Economy in Rolling-Mills. (Fuel Economist, 1927, Vol. 3, Oct., pp. 13-17). An illustrated account of the application of different types of bearings to rolling-mills for the reduction of power consumption. The Michell bearing, suitable only for cold-rolling, the Skefko roller bearing, and a type of roller bearing used in American mills are shown, and particulars are given of the economy effected by the use of bearings in rolling-mills.

Roller Bearings Cut Down Power Waste. S. M. Weckstein. (Iron Age, 1928, Vol. 121, Jan. 26, pp. 259-262). An illustrated account of the use of roller bearings as applied to roll necks, pinion stands, and hot saws in steel mills. Some of the advantages claimed for the use of these bearings are discussed.

Roll Neck Brasses for Sheet and Tin Mills. (Blast-Furnace and Steel Plant, 1928, Vol. 16, Jan., pp. 4-7, 11). A description of the procedure adopted in studying the service given by various types of brasses in different positions in the mill-stands. Such matters as the relative advantages of virgin and remelted metal for the castings, of casting to size and machining either on the backs only, or on the backs and in the bore, &c., are dealt with. It appears that there is no appreciable difference in the life of brasses used in the lead or in the drag side, whether top or bottom.

The Bowser System of Rolling-Mill Lubrication. (Iron and Coal Trades Review, 1928, Vol. 116, Mar. 9, pp. 338). The general arrangements of this lubricating system is shown. The dirty oil from the mill enters a receiving tank where the water and heavy impurities are removed. From the receiving tank the oil is pumped into a filter, where it is finally purified and delivered to a pressure tank which maintains a proper distribution of oil to the mill.

Lubrication of Roll Bearings with Grease Briquettes. J. Sieger. (Stahl und Eisen, 1928, Vol. 48, Mar. 1, pp. 264-265). An arrangement is shown for holding a square briquette of some special lubricating grease in position on the open side of the journal of the lower roll in a rolling-mill stand. A short note on economy in lubrication is given.

Lubricants and Bearing Metal Problems in Mills. K. Hopfer. (Stahl und Eisen, 1928, Vol. 48, Mar. 29, pp. 408-410). A discussion of the general conditions required to ensure good lubrication of mill bearings, with notes concerning the most suitable types of alloys for bearings subjected to heavy pressure. Lead alloys have come into much prominence lately as a substitute for the expensive tin-antimony alloys. The hardness of the lead may be increased by additions of barium, cadmium, or nickel, but such alloys are apt to show brittleness under shock. For the heaviest stresses, the best results are obtained with bronzes containing tin from 12 to 14 per cent., or, in special cases, up to 21 per cent.

"Sticking Point" and Viscosity [of Oils]. A. Baader and H. Gruber. (Archiv für das Eisenhüttenwesen, 1928, Vol. 1, Apr., pp. 653-654). The importance of determining the viscosity of oils for switches and for lubrication at different temperatures is discussed, and an apparatus for testing the viscosity of oils at low temperature is illustrated and its application is described.

Viscosity Measurements of Liquids and Tests of Viscosity Meters. S. Erk. (Mitteilung aus der Physikalisch-Technischen Reichsanstalt, V.-D.-I. Verlag 1927; Stahl und Eisen, 1928, Vol. 48, Jan. 26, p. 109). The usual methods of measuring viscosity are subjected to a minute

criticism, and the sources of inaccuracy of measurement are pointed out. A standard viscosity meter which eliminates the errors usually made in viscosity measurement was constructed and is now in use in the Reichsanstalt for the purpose of standardising other viscosimeters.

Reversing Blooming-Mill Practice. G. A. V. Russell. (Paper read before the American Society of Mechanical Engineers, Dec. 16, 1926: *abst.*, Mechanical Engineering, 1927, Vol. 49, Dec., pp. 1331-1334; Journ. I. and S.I., 1927, No. I. p. 886).

Modern Reversing Ingot Rolling-Mills. F. Funke. (*Zeitschrift des Vereines deutscher Ingenieure*, 1928, Vol. 72, Feb. 18, pp. 197-201). The author reviews the development of the reversing mill and describes, with plans and photographs, three 1150 mm. mills recently built for the Vereinigte Stahlwerke A.-G. Two have been erected in the August-Thyssen-Hütte, Hamborn, section of this Company, and the other at the Phoenix Works, at Duisburg-Ruhrort, of the same combine.

Details of Reversing-Mills. F. Funke. (*Zeitschrift des Vereines deutscher Ingenieure*, 1928, Vol. 72, Mar. 3, pp. 311-316). More complete details of the rolling-mills and the auxiliary plant at the August-Thyssen-Hütte, Hamborn, and the Phoenix Works, Ruhrort, are given.

The Manufacture of some Foreign Rails. C. W. Gennett, jun. (*American Institute of Mining and Metallurgical Engineers*, 1928, Technical Publication No. 47). The author gives figures showing the production and consumption of rails in the United States from 1849 to 1925. Imports of recent years have ranged from 10 to 20 per cent. of exports or 1 to 2 per cent. of total consumption. It is also noteworthy that the production of Bessemer rails, which reached 3,380,025 tons in 1907, had declined in 1925 to 9687 tons, or less than in any other year since 1869. The author describes in detail the testing of rails made at the Krupp works in Germany for the Boston and Maine R.R. Co., giving the results in tabular form. Two notable departures from American practice are outstanding features of the Krupp practice. One is the bottom casting of the ingots, and the other is the fact that all the rails are straightened by passing through a roller straightening machine. Freedom from segregation and piping are said to result from this method of bottom casting, with good effects on the finished rail. The results obtained by straightening in the roller straightening machine are recorded as a satisfactory advance in the finishing of rails.

The Manufacture of Sound Rails by the Courthéoux System of Rolling. L. Pichard. (*Génie Civil*, 1927, Vol. 91, Dec. 31, pp. 671-674). Weakness caused by segregation in the heads of rails is avoided by the Courthéoux process; the blooms are cut into two in the direction of

rolling, and it is then arranged that the rail head shall be formed from the sound metal constituting the outside of the ingot.

The Manufacture of Sound Rails. G. Charpy. (*Génie Civil*, 1928, Vol. 92, Mar. 10, p. 241). The author recapitulates a suggestion, made by him in 1918, for the production of sound steel for making rails. The position of the pipe in an ingot is indicated by a diagram, and the method for obtaining the maximum amount of sound metal is as follows: the ingot should be rolled on two faces only (that is, without turning), and the final passes should be such as to make the section of the material resemble three diamonds, the two outer ones joined by their corners to the opposite corners of the middle one. The two outer parts of the rolled material would then have comparatively little segregation at their top ends; the middle portion would, of course, be segregated through a greater length, and would be cropped off lower than the outer portions.

The Drafting and Rolling of Rails for Heavy Wagons and of the Hook-Fishplate for Jointing them. L. Becker. (*Archiv für das Eisenhüttenwesen*, 1927, Vol. 1, Dec., pp. 421-425). These rails were made specially for laying down on the 5 km. long high road connecting the city of Valencia with its harbour. They are of a channel form with a low flange at one side of the flat back, and are laid with the flat side level with the roadway. The rolls in which the rails were rolled were specially designed and drafted, as also were those for rolling the fishplates. The draft of the rolls is well illustrated.

The Principles of the Design of Pilger Rolling-Mills. G. B. Lobkowitz. (*Röhrenindustrie*, 1927, Vol. 20, Dec. 8, pp. 383-385). The present article is supplementary to one bearing the same title which appeared in *Stahl und Eisen*, 1927, Vol. 47, Aug. 4, pp. 1277-1283. The stresses in the rolls of a Pilger mill, and the form of the roll cone are given further mathematical consideration.

Oblique Rolling of Seamless Tubes. (*Engineering*, 1928, Vol. 125, Mar. 2, pp. 269-272). A translation is given of the Report by F. Kocks on his experimental and theoretical investigations of the oblique rolling of seamless tubes, which was presented to the Rolling Mill Committee of the Verein deutscher Eisenhüttenleute. (*See Journ. I. and S.I.*, 1927, No. I. p. 888.)

A Newly Constructed Seamless Tube Mill. C. A. Colgate. (*Blast-Furnace and Steel Plant*, 1928, Vol. 16, Feb., pp. 240-241, 248). The new 51-in. roll type piercing mill installed at the Ambridge plant of the Standard Seamless Tube Co. in America is described and illustrated. It is stated to be the largest of its type so far built in that country. The mill is entirely motor driven.

Reducing Tube Mill for Seamless Steel Tubing. (Iron Age, 1928, Vol. 121, Feb. 2, pp. 333). A new reducing mill for the manufacture of seamless steel tubing has been brought out by the Wellman-Seaver-Morgan Co., Cleveland. The mill has three rolls in the same plane in each housing. Each roll encloses 120° of the circumference of the tube. The roll stands are all practically alike except that the roll assembly is shifted 180° in each succeeding stand. The drive shaft always comes out in a horizontal line on the same side of the mill, and these shafts are driven through speed reducers by variable speed motors, each stand having its individual motor. This permits exact regulation of speed and the handling of various gauges and materials at the correct speeds.

Bethlehem's New Pipe Mills. G. A. Richardson. (Iron Age, 1928, Vol. 121, Apr. 19, pp. 1084-1089). The lay-out and equipment of the new pipe mills of the Bethlehem Steel Co., Sparrow's Point, are described and illustrated. There are two butt-weld and two lap-weld mills in operation for producing all sizes of pipes from $\frac{1}{8}$ in. up to 16 in. in diameter. The skelp heating furnaces, with hearths 9 ft. in width, are served by magnetic chargers. Particulars are also included of the galvanising department. The galvanised pipe is not dipped into water. It is stated that the elimination of this operation results in a better spangle finish and appearance.

The Mechanicalising of Semi-Continuous Merchant Mills. B. Quast. (Stahl und Eisen, 1928, Vol. 48, Feb. 2, pp. 141-142). This is a short description of a semi-continuous mill for rolling hoop iron, wire, rod, or merchant bars. It consists of a continuous roughing train of eight stands, with 350-mm. rolls, and a finishing train of four stands with 280-mm. rolls, three high. The rod coming from the continuous stands is fed into the first stand of the finishing rolls by the ordinary guide channel. It is then taken from stand to stand by two "return roller" apparatus, one of which is placed on either side of the finishing stands. Only one catcher is necessary at the last stand. The apparatus and layout are illustrated.

High Speed Continuous Rod Mill. J. Nelson. (Iron Age, 1927, Vol. 120, Nov. 10, pp. 1297-1299). Illustrated particulars are given of the new Morgan billet mill and rod mill at the South Works of the American Steel and Wire Co., Worcester, Mass. The billet mill has six stands of 18-in. rolls and reduces 5-in. blooms to 2-in. billets. The rod mill follows the general line of all Morgan double-strand mills, except that the rod is finished in two separate trains of rolls. Power required to drive these mills and auxiliary equipment is applied through 28 electric motors which total 7645 H.P. The new mill is the first in the United States to produce rods in 400-lb. bundles. It is also stated to be the first in the world to roll coils of this weight in so small a size as a diameter of 0.177 in.

Rolling of Hollow Staybolt Bars. (Iron Age, 1927, Vol. 120, Nov. 24, pp. 1451-1452). Particulars are given of a method for the manufacture of seamless hollow staybolts. The method consists in inserting a steel or iron pipe full of sand in the centre of a built-up faggot of rods, heating the faggot to welding temperature, and rolling. The sand core is afterwards removed by means of compressed air.

Mills of the Backed-Up Type Remove Cold Rolling Limitations. L. Jones. (Iron and Steel Engineer, 1927, Vol. 4, Dec., pp. 498-500). There are approximately five types of backed-up mills as follows: (1) The three-roll type, of which the Lauth plate mill is the leading example; (2) the four-roll backed-up mill, where each working roll has one supporting roll; (3) the six-roll mill, commonly called the cluster mill, where each working roll has two supporting rolls; (4) the seven-roll mill, or what might be termed the three-high cluster mill, having three working rolls, the top and bottom of these being supported by two backing-up rolls; (5) another type of the four-roll backed-up mill, which is a modification of the three-roll mill. Of these various types the three-roll is in most general use, with the four-roll and cluster types following in order as named. For the rolling of sheets and strip the four-roll type and the cluster type are better adapted than the three-roll type, and will eventually supersede it altogether. The relative merits of the four-roll and cluster type mills are enumerated as follows:

Four-Roll Type.—(1) Smaller number of rolls; (2) shorter distance from the edge of the housing to the centre of the mill.

Cluster Type.—(1) No bearings for holding the working rolls in alignment are necessary; (2) the working roll cannot wear out of alignment, hence the cluster mill operator does not experience the difficulty which the four-roll operator experiences, due to the terrific end thrust of the working rolls when they become slightly crossed; (3) the working rolls can be more quickly changed, as there are no bearings to handle; (4) the working rolls automatically align themselves when placed in the mill by coming in contact with the two supporting rolls, eliminating the human element in lining up the mill; (5) the contact pressure between the work rolls and the supporting rolls is approximately 30 per cent. less per in. of face on the cluster mill as compared with the four-roll mill; (6) the working roll is supported in both directions of force, and hence smaller diameter rolls can be used to accomplish the same work; (7) with equal diameter of working roll, and with the ratio of the backing up roll to the working roll approximately 2 to 1, which is the general ratio, the cluster mill has approximately 40 per cent. greater capacity.

Backed-Up Rolls of Several Types. L. Jones. (Paper read before the American Society of Mechanical Engineers: Iron Age, 1927, Vol. 120, Nov. 17, pp. 1374-1375).

Backed-Up Mills for Continuous Rolling. L. Jones (Mining and Metallurgy, 1928, Mar., pp. 133-135).

Developments in Four-High Rolling-Mills. F. C. Biggert, jun. (Paper read before the Iron and Steel Division of the American Society of Mechanical Engineers, Nov. 10, 1927; Blast-Furnace and Steel Plant, 1927, Vol. 15, Dec., pp. 567-570; Iron Age, 1927, Vol. 120, Nov. 17, pp. 1367-1370).

Four-High Mills and the Development of their Rolling Practice. F. C. Biggert, jun. (Paper read before the Joint Conference of Engineers' Society of Western Pennsylvania and the American Society of Mechanical Engineers, Apr. 3, 1928; Blast-Furnace and Steel Plant, 1928, Vol. 16, Apr., pp. 498-502). The chief object of the four-high mill is to provide an exceedingly rigid working roll of relatively small working diameter; consequently less pressure is necessary to produce a given reduction. The author discusses the subject under the following headings: pressures on the backing rolls, the advent of roller bearings, power saving by roller bearings, skill required in operation, holding long strip in the mill, proper contour of the rolls, changing of rolls, slippage due to unmatched rolls, effect of unequal roll diameters on mill, function of guides, and the control of roll shape by application of heat.

Sheet Steel for Automobile Bodies. (Blast-Furnace and Steel Plant, 1928, Vol. 16, Feb., pp. 245-248; Mar., pp. 368-373; Apr., pp. 489-491). A detailed non-technical discussion of the processes involved in the manufacture of sheet steel for automobile bodies. Defects in ingots, the influence of chemical composition, soaking-pit practice, blooming-mills, and the effect of ingot temperature on rolling are discussed. The rolling of sheet bars and the passes used are described, defects in blooms and sheet bars are touched upon, and the relation of gauge and bar weights is dealt with.

Manufacture of Bright Steel Sections, with Special Reference to Steam Turbine Blades. F. Braun. (Stahl und Eisen, 1928, Vol. 48, Jan. 26, pp. 97-101). A description of the hot-rolling, cold-rolling, and drawing operations in the manufacture of nickel steel and stainless steel turbine blades, including the intermediate processes of annealing and pickling, and notes on the drafting of the rolls employed.

The Cold-Rolling of Strip Steel. H. C. Uhl. (Iron and Steel Engineer, 1928, Vol. 5, Apr., pp. 171-177). The chief portion of this paper is devoted to an illustrated description of the electrical equipment of cold-rolled strip steel mills. The author also outlines the nature of the product, and discusses briefly pickling, annealing, preparation for shipment, and rolling-mill practice.

The Cold-Rolling of Steel Strip. C. E. Davies. (Iron and Steel Industry, 1928, Vol. 1, Jan., pp. 107-112; Feb., pp. 151-157; Mar., pp. 190-192). Descriptions of the general processes employed in the production of cold-rolled strip and some detailed notes and descriptions of the annealing plant, after which a study is made of the actual rolling equipment and the various designs and arrangements of cold strip mills as generally used in this country and abroad.

An Automatic Blooming-Mill for a Strip Steel Rolling-Mill. A. Schöpf. (Centralblatt der Hütten und Walzwerke, 1927, Vol. 31, Oct. 12, pp. 584-586).

Electricity's Contribution to the Iron and Steel Industry. (Iron and Steel Engineer, 1928, Vol. 5, Jan., pp. 27-62). A complete tabulated list is given of main roll drives installed in the iron and steel industry of the United States and Canada as at December 31, 1927. Information is presented showing the horse-power, r.p.m., voltage, cycles, type and size of mill, method of driving, date of purchase, name of plant, and location. A classified list is also included, which gives the types of installations in the various kinds of mills.

Large Expansion in Electric Drive. S. G. Koon. (Iron Age, 1928, Vol. 121, Apr. 5, pp. 939-940). Particulars are given showing the extent of the use of electric drives in rolling-mills in the United States. The present installations aggregate 1510 units of a total horse-power of nearly 2,000,000.

Electrification of Rolling-Mills in 1927. J. D. Wright. (Blast-Furnace and Steel Plant, 1928, Vol. 16, Jan., pp. 31-33). An enumeration of the types of motors and equipment for driving skelp, continuous, structural, blooming, bar, and merchant mills. Several important new mills are briefly mentioned.

Electric Drives in the Steel Rolling-Mills. A. F. Kenyon. (Blast-Furnace and Steel Plant, 1928, Vol. 16, Jan., pp. 24-27). A review is given of important installations of continuous and reversing mills in America, together with a brief discussion on the use of synchronous motors.

Recent Developments in Electric Drives for Rolling-Mills. L. A. Umansky. (Journal of the American Institution of Electrical Engineers, 1927, Sept., p. 885; *French abstr.*, Revue Universelle des Mines, 1928, Vol. 17, Feb. 15, pp. 185-190). Various arrangements of electric drives for operating continuous mills are described.

40-in. Reversing Blooming-Mill, Wisconsin Steel Company. F. A. Wiley. (Iron and Steel Engineer, 1928, Vol. 5, Mar., pp. 120-126). The general arrangement of this blooming-mill is shown, and a detailed

description is given of the electric driving equipment. It is stated that the 7000 H.P. reversing motor was the first of such large single armature machines supplied with power from d.c. generators in parallel to be placed in service.

Electrical Equipment of Plate Mills. (Electrician, 1927, Vol. 99, Nov. 25, pp. 653-654). The Consett Iron Co.'s electrically driven plate mills are illustrated and described. The company generates its own power; a.c. is used for the continuous running-mills (32-in. Lauth light plate mill and 30-in. chequer mill, both with 6 ft. 6 in. rolls), but d.c. is supplied through flywheel equaliser sets to the reversing mills (40-in. two-high slabbing mill with 8 ft. 6 in. rolls, and 42-in. two-high plate mill with 9 ft. 6 in. rolls). The live rolls, screw-down gear, manipulators, mangles, cranes, &c., are operated on d.c.

Frequency Converter Speed Sets for the Carnegie Steel Company, Upper Union Works, Youngstown, Ohio. G. P. Wilson. (Iron and Steel Engineer, 1927, Vol. 4, Dec., pp. 487-490). Particulars are given of the electric driving equipment for the merchant mills at the Upper Union Works of the Carnegie Steel Co. The 10-in. hoop mill is driven by 1-1600 H.P., 493 r.p.m., 3-phase, 60 cycle, 6600 v. constant speed wound rotor induction motor. This motor is arranged with shaft extension for the addition of speed regulating equipment at some future date. The 10-in. bar mill is driven by 1-1600 H.P., 493 r.p.m., 3-phase, 60 cycle, 6600 v. wound rotor induction motor, with speed regulating equipment for definite speeds of 5 and 10 per cent. above and below base speed. The motor for the 12-in. bar mill is a duplicate of that driving the 10-in. mill. The layout of this mill is very similar to that of the 10-in. bar mill. The 8-in. bar mill is driven by 1-700 H.P., 493 r.p.m., 3-phase, 60 cycle, 6600 v. wound rotor induction motor with speed regulating equipment for definite speeds of 5 and 10 per cent. above and below the base speed.

The 7-in. hoop mill is equipped with two motors, 1-450 H.P., 743 r.p.m., constant speed, 3-phase, 60 cycle, 6600 v. wound rotor induction motor driving roughing mill, and 1-700 H.P., 405 r.p.m., constant speed, 3-phase, 60 cycle, 6600 v. wound rotor induction motor with shaft extension for speed regulating equipment to be added later. This motor drives the finishing stands. The 8-in. hoop mill is driven by a motor similar to the motors driving the 7-in. hoop mill.

The equipments are arranged with motor, slip rings, and converter on a common bedplate and shaft.

Ten-Stand Continuous Sheet Bar Mill. R. A. Fiske. (Iron Age, 1928, Vol. 121, Mar. 22, pp. 799-802). **Continuous Mill will Supply Bars for Tinplate Division.** F. B. Pletcher. (Iron Trade Review, 1928, Vol. 82, Mar. 22, pp. 749-751). The layout and equipment of

the new two-high 21-in. continuous sheet bar and skelp mill at Indiana Harbour are described and illustrated. The mill comprises ten horizontal stands and three edging stands. The first three stands make up the roughing section of the mill and are driven by a 3600 H.P. motor through reduction gears and three sets of bevel gears. Following these stands is an 18-in. edger driven by a separate motor. Stands 4, 5, 6, and 7 are known as the intermediate section of the mill and are driven by a 4040 to 7500 H.P. motor through four sets of bevel gears. A 16-in. edger is located between stands 5 and 6 and is driven by the same motor. A similar edger, independently driven, is placed between stands 7 and 8. The three finishing stands, Nos. 8, 9, and 10, are driven by separate d.c. variable speed motors, each rated at 2000 H.P., 86 to 165 r.p.m., 600 v.

Main Drives 10-in. Merchant Mill at McKinney Steel Co. A. F. Kenyon. (Iron and Steel Engineer, 1927, Vol. 4, Nov., pp. 455-457). This mill has a roughing train driven by a 1000 H.P., 200-600 r.p.m. motor, an intermediate train driven by a 2000 H.P., 137-175 r.p.m. motor, and four finishing stands driven by a 1200 H.P., 300-550 r.p.m. motor. On account of the wide speed range and comparatively large size of the 1000 H.P. motor, the best performance was obtained by building this motor as a double armature machine. The 2000 H.P. and 1200 H.P. motors are both single armature machines. Alternating current is supplied to the mill at 6600 v. three-phase from the company's 25 cycle power system. Synchronous motor-generator sets located in the mill sub-station convert the 25 cycle power to direct current at 600 v. for the main drives, and 250 v. for the auxiliaries.

Synchronous Motors for Driving Mills. W. T. Berkshire and H. A. Winne. (Paper read before the American Institute of Electrical Engineers, Nov. 29, 1927: Blast-Furnace and Steel Plant, 1927, Vol. 15, Dec., pp. 586-590, 596; Iron Age, 1928, Vol. 121, Feb. 2, pp. 529-530). The conditions to be met in different types of mills are discussed and the characteristics of various classes of motors which may be used are considered.

Accurate Control of Rolling Speeds. (Iron Age, 1928, Vol. 121, Feb. 2, pp. 325-327). The new 10-in. merchant mill at the Union Works of the Bourne-Fuller Co., Cleveland, is described and illustrated. The new mill is semi-continuous, with two groups of four stands of roughing rolls arranged in tandem, and four finishing stands. The first four roughing stands are driven by a single motor. The second group of roughing stands have individual motor drives, while three motors drive the finishing rolls. Unusual provision has been made for close regulation of rolling speeds, resulting in less frequent roll changes. When rolls are to be changed the entire housing is lifted by cranes and taken to the set-up stands. It is claimed that a one-piece housing

makes a more solid mill. Direct current for driving the mills and various auxiliary equipment is derived from two motor-generator sets. Each consists of a 1000 kw. 250 v. direct current generator driven by a 1400 kva. 2300 v. synchronous motor with 80 per cent. power factor. All mill motors are of the same type and have a speed of from 267 to 800 r.p.m.

New Drive for Three-High Plate Mills. J. Taylor. (Iron Age, 1928, Vol. 121, Apr. 12, p. 1004). Brief particulars are given of the arrangement of a rolling-mill slip drive. It has been in use on two-high reversing plate mills and is now being applied to three-high mills. The customary pinions and pinion housings have been eliminated, their place being taken by a light nest of gears between the flywheel and the spindles. The torque is applied to the centre roll, and the flywheel may be speeded up about 30 per cent., giving smoother operation.

Development of Electrotechnical Apparatus in Ironworks. E. Courtin. (Stahl und Eisen, 1927, Vol. 47, Nov. 17, pp. 1941-1954).

Practical Experiences with Electrical Installations in Iron and Steel Works. G. Liss. (Stahl und Eisen, 1927, Vol. 47, Dec. 8, pp. 2067-2074).

ROLLING-MILL MACHINERY.

Motor Rollers. A. M. MacCutcheon. (Iron and Steel Engineer, 1928, Vol. 5, Feb., pp. 95-99). The application of motor rollers to rolling-mills is discussed. Each roller is driven by a motor contained within the roller shell. The squirrel cage winding with its core is contained in the shell of the roller and the stator core and its winding are mounted on a stationary shaft. The shell or outside rotating part is supported from the stationary shaft by means of ball or other type of anti-friction bearings supported in suitable housings. The main field of application of these rollers is on continuous duty non-reversing tables such as the run-out tables of hot strip and bar mills.

New Roll Grinder. (Iron Age, 1928, Vol. 121, Feb. 2, pp. 338-339). Brief illustrated particulars are given of a 24-in. swing, self-contained, plain roll grinder, a feature of which is the forced-feed table lubrication.

The Dressing of Rolls by Grinding. H. J. Pratt. (Blast-Furnace and Steel Plant, 1928, Vol. 16, Feb., pp. 242-244). The author touches upon the history of roll grinding and outlines the advantages of this method of dressing rolls.

Billet-Handling Magnet and Crane. (Iron Trade Review, 1927, Vol. 81, Dec. 1, p. 1357). Describes a billet-handling magnet and crane in operation at an American plant. The equipment consists of an overhead crane and a lifting magnet of the bipolar type. The control box containing a row of push buttons is carried by a strap around the operator's neck. The use of this magnet has released eight men for other work.

Devices for Doubling Steel Sheets. W. Krämer. (Stahl und Eisen, 1928, Vol. 48, Apr. 5, pp. 444-446). The article illustrates various machines of new design by Krupp and by "Demag" for the doubling of steel sheets.

Sheet Pack Opener. (Iron Age, 1928, Vol. 121, Jan. 26, p. 271). Brief particulars are given of a mechanical sheet pack opener in operation at the mills of the Youngstown Sheet and Tube Co. The machine consists of a set of horizontal rods arranged one above the other, and a travelling gripper head into which the sheets are introduced. The slightly opened sheets are inserted between the rods. A sweeper arm pushes the sheets into the openings in the gripper block. The ends of the sheets are clamped, and the backward movement of the gripper block pulls the sheets over the rods and separates them. The machine is operated by three men.

Large Sheet Pack Opener. (Iron Age, 1928, Vol. 121, Mar. 15, p. 736). Brief particulars are given of a sheet pack opener designed to handle 60 × 120 in. sheets when passing through the machine at an angle of 150°. Longer and wider sheets can also be dealt with if straightened before passing through the rolls. The machine can be operated from either side and moved from one place to another.

Continuous Sheet Shears. (Iron Age, 1927, Vol. 120, Oct. 27, pp. 1160-1161). Brief illustrated particulars are given of an automatic continuous shearing machine for sheets and tinplate. The packs are inserted lengthwise, curl end first, between two caterpillar conveyors, and are carried to side cutting shears and afterwards to end cutting shears. Here the cutting off of the curl or front end is controlled by means of an electric switch, situated on the shear bed, which is adjustable to provide for shearing any amount ranging from $\frac{1}{2}$ in. to several inches. The pack then passes on to the back gauge, where the pack is cut up to any size multiples of sheets desired. The conveyor is equipped with pressure pads, which flatten out the packs.

New Bloom Shear. (Blast Furnace and Steel Plant, 1927, Vol. 15, Dec., pp. 597-598). A brief illustrated description of a large bloom shear built by the United Engineering and Foundry Co. It has a capacity of 5,500,000 lb. between the knives and will cut 3 in. by 36 in.

or 5 in. by 22 in. cold steel blooms. Its stroke is $6\frac{3}{4}$ in., and it runs at 12 cuts per minute. The overall height is 20 ft., and it is driven by a 250 H.P. electric motor. The ram is balanced at all points by a compensating spring balance. A special pusher feeds short pieces and ejects crop ends. Distant control and a motor-operated gauge are other features.

Capacity of Sheet Shear Increased. P. J. Edmonds. (Forging, Stamping, Heat Treating, 1927, Vol. 13, Nov., p. 443). A brief description is given of a mechanical aid by which one man is enabled to shear 60,000 lb. of material in $8\frac{3}{4}$ hrs. on a 120-in. shearing machine, as compared with 20,000 lb. sheared by two men without such assistance. Auxiliary rolls carry the cut material from the machine and stack it on a skid resting on a truck; the operator, being freed from this part of the operation, can start fresh sheets into the machine much sooner.

Open Throat Shear. (Blast-Furnace and Steel Plant, 1928, Vol. 16, Mar., p. 396). The large shear illustrated in this note is capable of cutting $4\frac{1}{2}$ in. square or 5 in. round cold alloy steel; the knife pressure is 1,400,000 lb. The shear stroke is $6\frac{1}{2}$ in., and a 125 H.P. motor drives it at 15 cuts per minute. An automatic band brake holds the ram at the top of its stroke when work is not being cut.

Continuous Automatic Shearing Machine. (Blast-Furnace and Steel Plant, 1927, Vol. 15, Dec., pp. 598-599). A brief illustrated description of the Streine Tool and Manufacturing Co.'s automatic sheet and tinplate shears. An important part of the tinplate shear is a caterpillar conveyor which exerts a powerful pressure on the packs and flattens them out so that the sides are cut truly parallel. The side cutting shears are accurately controlled to within $\frac{1}{64}$ in.

A New Labour-Saving Machine. (Blast-Furnace and Steel Plant, 1927, Vol. 15, Dec., p. 597). **Ingot Turning Machine.** (Iron Age, 1928, Vol. 121, Jan. 26, p. 270). A brief illustrated description of the Wellman-Seaver-Morgan Co.'s new electrically operated machine for turning and pushing the tapered ingots, used for the manufacture of tubes by the Pilger process, in the heating furnace.

Rolling-Mill Rod-Switching Device. (Machinery, 1928, Vol. 31, Jan. 12, p. 496). An automatic rod-switching device is described. The switch pipe, which controls the direction which each new length of wire rod shall take in order that it may reach the empty coiler (two coilers are used), is supported at its movable end in a fork formed at the end of an inverted T-shaped lever, pivoted at the junction of the arms. The arms carry buckets with a small outlet at the bottom, and water is admitted to the one or other by a three-way tap controlled

by the position of the T-lever. While a wire rod is passing to one coiler, the corresponding bucket is in the lowered position, its water supply is cut off and it is emptying itself; meanwhile the other bucket is filling, the incoming water flowing faster than the outflow. Consequently, as soon as the tail end of the wire rod passes out of the switch pipe the heavy bucket sinks and pulls the switch over, so diverting the next rod to the other (empty) coiler.

Heavy Machining at Steelworks. (American Machinist, European Edition, 1928, Vol. 67, Feb. 4, pp. 304E-306E). Heavy machine work, such as turning tyres for locomotives and cement kilns, large spherical seats, circular planing coupling shafts, at Messrs. Edgar Allen & Co.'s works, are illustrated and briefly described.

MANUFACTURE OF WIRE.

The Cold-Rolling of Steel Wire. M. von Schwarz and H. Goldschmidt. (Stahl und Eisen, 1928, Vol. 48, Mar. 1, pp. 265-268; *abstr.*, Metallurgist, 1928, Apr. 27, pp. 59-60). Trials are described with the object of substituting a cold-rolling process for the drawing process in the manufacture of wire, and a machine has been devised for rolling wire rod of 5 mm. diam. down to 1 mm. in 12 or 16 passes. The roll draughting is illustrated, and records of the reduction in the several passes and of the tensile strength of the wire from the first to the last pass are given. It is claimed that pickling the rod is rendered unnecessary, and a good scour is all that is required before rolling.

The Cold-Rolling of Steel Wire. H. Goldschmidt. (Wire, 1928, Vol. 3, Feb., pp. 43-46). The usual practice of manufacturing iron wire is to hot-roll down to 5 mm. diameter and then cold-draw for the thinner grades. For the latter process to be economically successful the iron oxide film must be removed by pickling, as mechanical cleaning is not sufficient. The article describes an experiment in which the cold-drawing was replaced by cold-rolling in order that mechanical removal of the oxide might be employed. The drafting of the rolls is detailed and the microstructure of the wire produced is illustrated and commented upon.

The Manufacture of Steel Wire. G. A. Alder. (Proceedings of the Cleveland Institution of Engineers, Session 1927-28, No. 2, pp. 37-69; Iron and Coal Trades Review, 1927, Vol. 115, Dec. 9, p. 862; Dec. 16, pp. 891-892). The paper opens with a description of the cleaning of wire rods, and goes on to describe subsequent operations—*i.e.* blueing, wet drawing, heat treatment, patenting, and galvanising. The effects of lead bath cooling in the patenting process and the action of galvanising

on the physical properties of the steel are shown. The paper concludes with a table showing the result of physical tests of wire at various stages of drawing.

The Plants of Pittsburgh Steel Company. (Blast-Furnace and Steel Plant, 1928, Vol. 16, Jan., pp. 63-73). An illustrated description of the plants, equipments, and methods of operation. The wire plant (wire, nails, wire fencing, &c.) and tube mills are of especial interest.

Some Useful Charts for the Wire Drawer. W. D. Pierson. (Wire, 1927, Vol. 2, Oct., pp. 348-349). Three charts are reproduced showing the relationships between the diameter and area, area and elongation, and diameter and elongation, as these change when a wire is drawn to a smaller size.

The Drawing of Round Wire. J. D. Brunton. (Wire, 1927, Vol. 2, Oct., pp. 342-344, 358-363). A description of wire-drawing machines in use in British shops.

Important Factors in Wire-Drawing. J. D. Brunton. (Wire, 1927, Vol. 2, Nov., pp. 388-389, 404-405). The influence of drawing speed, reduction, and other factors are discussed.

The Drawing of Profile and Shaped Wire. J. D. Brunton. (Wire, 1927, Vol. 2, Nov., pp. 379-382). An outline of the process is given. The cold-work put into the wire makes it often possible to employ a cheaper straight carbon steel instead of a more expensive alloy steel; in addition, the cost of production of small parts, such as rocker arms, by cutting them off from lengths of profile wire is much lower than that of producing them by forging, heat-treating, and milling. Various types of dies are described.

Power Consumption and Flow of Metal in Wire-Drawing. J. D. Brunton. (Wire, 1928, Vol. 3, Mar., pp. 79-80).

A Wire-Straightening and Cutting-Off Machine. (Machinery, 1928, Vol. 31, Mar. 1, pp. 702-703). A small bench machine for straightening and cutting off wire from the coil into lengths for rivets and similar pieces is described.

FURTHER TREATMENT OF IRON AND STEEL.

PYROMETRY.

Pyrometric Regulation of Heat-Treating Operations. W. P. Wood. (Fuels and Furnaces, 1928, Vol. 6, Mar., pp. 347-350). The author emphasises the importance of obtaining correct furnace temperatures in heat-treating operations.

Thermocouple Pyrometers in Works and Laboratories. A. Blackie and C. W. Ockelford. (Journal of Scientific Instruments, 1927, Vol. 4, No. 24; *abstract*, Engineering, 1927, Vol. 124, Dec. 30, p. 858). The authors describe the system of control adopted at H.M. Fuel Research Station to check the readings given by thermocouples of both the laboratory and the works types.

Platinum/Platinum-Rhodium Thermo-Electric Couples. A. Sourdillon and Rolet. (Revue de Métallurgie, Mémoires, 1928, Vol. 25, Feb., pp. 90-97). The tests carried out show clearly that it is gases containing sulphur which bring about the rapid corrosion of platinum wires; no thermal treatment was found capable of stopping it. Whereas metallic protection was not satisfactory, silica offered a perfect protection. A badly protected couple soon shows points of corrosion; this corrosion does not introduce errors into the measurement of temperatures, provided the whole of the corroded zone is brought to a strictly uniform temperature—a condition not usually obtained with the ordinary type of thermocouple. During the standardisation of thermocouples, a test should always be made for "parasite couples."

The Measurement of High Temperatures by Means of a Tungsten-Molybdenum Thermocouple. D. Binnie. (Royal Technical College Metallurgical Club Journal, 1927-28, No. 6, pp. 35-36, 42).

HEAT-TREATMENT EQUIPMENT.

Furnace Development in Heat-Treating and Forging. W. M. Hepburn. (Transactions of the American Society for Steel Treating, 1928, Vol. 13, Jan., pp. 126-141). A brief outline is given of developments 1928-i.

in heat treatment and forging furnaces, and several modern gas-fired installations are described.

Furnaces Burning Manufactured Gas. A. J. Smith. (Forging, Stamping, Heat Treating, 1927, Vol. 13, Oct., pp. 403-404). Describes the construction and operating results of gas-fired furnaces of a type suitable for annealing, normalising, carburising, reheating, or heating for forging.

Continuous and Automatic Gas Heat-Treating. J. B. Nealey. (Wire, 1928, Vol. 3, Jan., pp. 8-9, 33). An enumeration of several processes carried out on wire or strip, such as annealing, hot galvanising, japanning, &c., in which automatically controlled gas-fired furnaces are used.

Construction and Operation of Kathner Normalising Furnaces. C. P. Mills. (Paper read before the Joint Conference of Engineers' Society of Western Pennsylvania and American Society of Mechanical Engineers, Apr. 3: Blast-Furnace and Steel Plant, 1928, Vol. 16, Apr., pp. 502-505). The furnace is equipped with both oil and gas burners, and consists of a heating zone 75 ft. long and a cooling zone 80 ft. long. The sheets are conveyed through the furnace on rollers. A special feature is the complete insulation of the bottom, side walls, and roof.

Equipment and Operation of a Heat-Treating Plant. M. G. Jewett. (American Machinist, European Edition, 1928, Vol. 68, Mar. 3, pp. 171-172). The equipment of the heat-treating department of the Chain Belt Co., Milwaukee, consists of four rotary carburising furnaces, two rotary drawing furnaces, and one rotary, continuous heat-treating furnace, and a Greene quenching machine. The air is supplied by three Spencer blowers. The plant operation is briefly described.

New Gas-Fired and Oil-Fired Furnaces. J. Fallon. (Paper read before the Birmingham Association of Mechanical Engineers: Iron and Coal Trades Review, 1928, Vol. 116, Mar. 9, pp. 340-341). The author gives some illustrated particulars of several new types of furnaces for the heat treatment of tubes and wire. An oil-fired billet furnace and an enamelling furnace are also shown.

Heat-Treatment Plant at the Associated Daimler Co.'s Works, Southall, Middlesex. (Machinery, 1928, Vol. 31, Jan. 12, pp. 485-486). There are 15 oil-fired muffles, 6 for carburising and 9 for heat treatment. There are 5 quenching tanks, 8 ft. in diam., 3 for oil and 2 for water quenching. An electric overhead charging machine serves all the furnaces, and the quenching tanks, which are situated in front of the furnaces.

Heat-Treating 3000 Automobile Bumpers Daily. R. A. Fiske. (Iron Age, 1928, Vol. 121, Feb. 9, pp. 391-393). **Heat-Treating Automobile Accessories on Mass Production Basis.** J. B. Nealey. (Iron Trade Review, 1928, Vol. 82, Jan. 19, pp. 199-201). The practice at the plant of the Stewart-Warner Speedometer Corporation, Chicago, for the heat treatment of automobile parts is described and illustrated. The equipment includes two special conveyor type gas-fired furnaces, one for hardening and one for drawing. Town gas is used for practically all the heat-treating operations. To assure a non-oxidising flame, the gas is mixed with air in a central plant, the proportions being one part of gas to one and a half parts of air. Compressors raise the air-gas mixture to a pressure of 25 oz. per sq. in. for distribution throughout the plant. The hardening furnace is constructed with an overhead combustion chamber, separated from the work chamber by a perforated arch which acts as an accumulator and distributor for the heating gases. The gases are withdrawn through flues in the side walls which connect with cross-flues under the hearth.

Ford's and the Heat Treatment of Steel. J. W. Urquhart. (Machinery, 1928, Vol. 31, Jan. 5, pp. 462-463). The author comments upon heat-treatment practice of the Ford works.

Heat-Treating Rifle Barrels of Stainless Steel. J. B. Nealey. (Iron Trade Review, 1927, Vol. 81, Dec. 1, pp. 1352-1354). An illustrated account of the equipment and methods employed for the heat-treating of rifle barrels of stainless steel at the plant of the Winchester Repeating Arms Co.

Strip Steel Annealed, Galvanised, and Japanned in Continuous Heat-Treating Equipment. J. B. Nealey. (Fuels and Furnaces, 1928, Vol. 6, Apr., pp. 525-526, 540). A brief discussion of the methods employed at the Acme Steel Co., Chicago, for the annealing, electroplating, galvanising, and japanning of strip steel. The several operations are exactly synchronised, heating, annealing, pickling, washing, galvanising or other treatment, washing and rewinding being carried out in one continuous operation.

Automatic Heating and Heat-Treating Units Synchronise Auto Production. J. B. Nealey. (Iron Trade Review, 1928, Vol. 82, Feb. 2, pp. 315-377).

Spring Heat-Treating Furnace Automatically Controlled. F. Stones. (Fuels and Furnaces, 1928, Vol. 6, Mar., pp. 373-376). Illustrated particulars are given of the plant and equipment of the Eaton Spring Corporation, Detroit, for the heat treatment of automobile springs. The plant consists of a hardening furnace, cambering machine, and

tempering furnace. The furnaces are oil-fired, and are provided with automatic temperature control apparatus.

Continuous Annealing Furnaces. F. W. Manker. (Paper read before the Engineers' Society of Western Pennsylvania, Dec. 1, 1927: *Heat-Treating and Forging*, 1927, Vol. 13, Dec., pp. 501-504; 1928, Vol. 14, Jan., pp. 47-50, 54). The advantages of continuous annealing over other methods of annealing are fully discussed, particularly from the economic point of view. Progress in the art of, and equipment for, annealing steel sheets and patenting wire is reviewed.

Annealing Sheet-Metal Shells in a Semi-Continuous Furnace. F. W. Curtis. (*American Machinist*, European Edition, 1927, Vol. 67, Dec. 31, pp. 801-802). The shells to be annealed are placed in sheet-metal frames, which are pushed by compressed air through the half-muffled type, oil-fired furnace; they emerge at the other side of the furnace. Each frame stands on a cast-iron base plate, and, in order to avoid the loss of the heat which the latter carries out of the furnace, it is quickly returned to the loading side, where another loaded frame is placed on it and pushed into the furnace again.

Production Heat Treatment of High-Speed Steel. E. N. Brookings. (*American Machinist*, European Edition, 1927, Vol. 67, Dec. 3, pp. 641-643). The process and equipment described are the outcome of experiments and practical experience of the heat treatment of large batches of such articles as thread taps, threading dies, lathe tools, &c. Two tandem gas-fired furnaces for preheating and heating for hardening, and an oven-type electric furnace for tempering, are used. An electric bell, actuated by a clock controlled by a switch at the furnace, gives notice when the correct hardening period has elapsed. The temperature of the preheater is hand-controlled, but the other two furnaces are automatically governed. The method of loading parts into the furnace is described.

Electric v. Fuel Furnaces. J. W. Urquhart. (*Machinery*, 1928, Vol. 31, Feb. 2, pp. 595-596). The advantages and disadvantages of the methods of heating heat-treatment furnaces are discussed.

The Homo Tempering Equipment. (*Machinery*, 1927, Vol. 31, Dec. 29, pp. 429-430). A special type of automatically controlled furnace is used. The heating elements are contained in an annular space surrounding the heating chamber proper, and the heat is conveyed to the parts under treatment by the forced circulation of air past the heating elements and through the pieces. It is claimed that more uniform heating is possible in this way, especially as the direction in which the heated air passes through the pieces is reversed frequently.

The Construction of Electric Furnaces for Hardening, Heating, and Enamelling. H. Nathusius. (Feuerfest, 1928, Vol. 4, Jan., pp. 3-5). The construction of electric resistance furnaces, the adaptation of electric resistances for use in electric furnaces, materials of construction for electric resistance furnaces, and the advantages of the latter over fuel-fired furnaces, are described.

Electric Furnace for Heating Drill Steel. H. K. Fox. (Electrical World, Nov. 20, 1926; Forging, Stamping, Heat Treating, 1927, Vol. 13, Oct. pp. 410-411). The construction and advantages of an electric furnace for heat-treating drill steel are described; the capacity and current consumption are tabulated.

Rotary Hearth Furnace Automatically Discharges Parts into Quenching Tank. (Fuels and Furnaces, 1928, Vol. 6, Feb., pp. 197-200). Illustrated particulars are given of an electric furnace with a rotary hearth and provided with time and temperature controllers for automatically discharging parts into the quenching tank. Two tanks, one for oil and the other for water, are situated alongside of the furnace, and by means of a double shute parts may be diverted into either tank.

Several Heat-Treating Operations Performed Simultaneously in Electric Counter-Flow Furnace. I. S. Wishoski. (Fuels and Furnaces, 1928, Vol. 6, Jan., pp. 93-96). The author describes the arrangement of an electrically heated furnace of the counter-flow type, in which automobile parts are carburised, annealed, and normalised simultaneously. The furnace has three independent chambers, through each of which the material is carried in boxes arranged in two parallel lines moving in opposite directions. Each chamber consists of a preheating zone, heating zone, and cooling zone.

Notes on a Project for an Electric Cementation Furnace. L. Delsaux. (Fonderie Moderne, 1928, Vol. 22, Jan. 10, pp. 3-6).

Wild-Barfield Electric Furnaces. (Machinery, 1928, Vol. 31, Feb. 9, pp. 617-619). Several types of this make of furnace are illustrated and briefly described. The hardening furnaces are provided with the necessary secondary windings for determining the correct quenching temperature by electro-magnetic means; at that temperature the steel becomes non-magnetic, which fact is recorded by an indicator attached to the secondary windings.

Electric Elevator Furnace Anneals Steel Castings. L. M. Bassini. (American Machinist, European Edition, 1928, Vol. 68, Mar. 3, pp. 161-163). The furnace described is of the car-bottom type, but in order to make the track space under it available while the furnace is

in use, it is supported high above the floor. The car bottom, when loaded, is run under the furnace and raised into position by a hydraulic lift. Special sand is used to seal the joint between the bottom and the furnace body. The furnace and the pumps for supplying the oil pressure to actuate the elevator are electrically operated.

An Electric Tube-Annealing Furnace. (Röhrenindustrie, 1927, Vol. 20, Dec. 22, pp. 406-407). An electric resistance furnace of the car-bottom type, for the annealing of tubes, is described. Details of its use in practice (time of annealing, temperatures, current used, &c.) are tabulated.

Selecting Electric Heat-Treating Equipment. (Machinery, 1927, Vol. 31, Dec. 1, pp. 257-259; Dec. 8, pp. 313-315). The features required in electric heat-treating furnaces are discussed.

Heating by Electricity and the Cost. C. L. Ipsen. (Heat Treating and Forging, 1928, Vol. 14, Feb., pp. 175-178). In this analysis of the cost of heating the author takes into account not only the initial expenditure on electric current, but all contributory items as well.

Conveyor Belt Acts as Furnace Floor. (Iron Age, 1927, Vol. 120, Oct. 27, pp. 1158-1159). An illustrated account is given of a continuous heat-treating furnace designed for heating and tempering cap screws. The overall length of the furnace, including a quenching tank, is 37 ft., and the hearth 16 ft. Work is carried through the furnace on an endless conveyor of stainless iron. The furnace is gas-fired.

CEMENTATION AND CASE-HARDENING.

Gas Carburisation of Steel. R. G. Guthrie and O. Wozasek. (Transactions of the American Society for Steel Treating, 1927, Vol. 12, Dec., pp. 853-870). The authors deal with the use of town gas for carburising purposes. The following problems were investigated: (1) Variation in depth and concentration of case from charge to charge or from day to day—no variation was found in different parts of the same charge; (2) the constituents of the gas responsible for the carburisation of steel; (3) the mechanism of carburisation; and (4) factors affecting the mechanism. The gas used was a mixture of coke-oven gas and blue-water gas, such as is supplied for domestic and industrial purposes in the Chicago district. The results show the advantages to be gained from treatment of the carburising gas at the furnace, and catalysing the steel in the furnace at the beginning of the run.

The Carburisation of Steel. H. B. Northrup. (Fuels and Furnaces, 1928, Vol. 6, Jan., pp. 61-66). The composition of steels suitable for carburising is shown, and the methods of carburising are briefly discussed.

Practice in the Carburisation of Steel. J. D. Gat. (Forging, Stamping, Heat Treating, 1927, Vol. 13, Oct., pp. 393-396). The factors which have an influence on the quality and properties of the final products, such as the manner of packing, the carburising agent used, energisers, &c., are discussed.

Remarks on the Soft Spots Observed, after Quenching, on Certain Cemented Pieces. J. Tonneau. (Aciers Spéciaux, 1928, Vol. 3, Jan., pp. 47-48). Sulphur is a frequent cause of the occurrence of soft patches on parts that have been case-hardened. The atmosphere of the heating furnace for quenching should be very slightly oxidising to keep the sulphur in the gases in the form of SO_2 . The parts should not be charged too soon after the gas-producers have been recharged or cleaned. Quenching in brine is advocated. The steel itself must, of course, be of good quality, and segregation must not appear at the surface.

Case-Hardening : Lead Coating as a Protection against Carbon Absorption. H. Graefe. (Werkstattstechnik, 1927, Vol. 21, Sept. 15, pp. 521-523). The author describes the lead-coating of machine parts in order to localise the effect of carburising media in case-hardening.

The Application of Nitrogen to the Surface Hardening of Steel. V. O. Homerberg. (Fuels and Furnaces, 1928, Vol. 6, Jan., pp. 29-33). The author has studied the physical properties of chromium-aluminium steel and chromium-aluminium-nickel steel case-hardened with gaseous ammonia, and presents the results of tests. Wear tests of these steels have shown them to be superior to other steels in resistance to metal-to-metal wear. Exposure to weather conditions and to water and salt sprays have demonstrated their superiority to the ordinary stainless steel in rust-resisting properties. Photomicrographs show the nitrided case after nitriding for 90 hrs. at 900°F . A layer, which etches very slowly, is at the surface, and is followed by a layer which etches very rapidly. This second layer merges into the core structure. For a short distance below this second layer the hardness is considerably above that of the core itself. It is often very difficult to determine the line of demarcation between the case and the core, especially when the nitriding is performed on heat-treated specimens.

Hardening by Nitrogenation. (Kruppsche Monatshefte, 1927, Vol. 8, Dec., pp. 208-212). Krupp's method of hardening steel by

nitrogenation is briefly described, and its advantages over cementation are enumerated.

Hardening by Nitrogenation. (Kruppsche Monatshefte, 1928, Vol. 9, Mar., pp. 46-52). Methods for hardening by nitrogenation such objects as shafts, crankshafts, patterns, guide rods, and similar parts, are briefly described.

Nitralloy and the Nitriding Process. H. A. De Fries. (Machinery, 1928, Vol. 31, Jan. 12, pp. 478-479). Nitralloy is the general name given to a number of special alloy steels which can be surface-hardened by the action of ammonia gas for from 2 to 90 hrs. at a temperature of about 875° F. without subsequent quenching. The carbon content ranges from 0.10 to 0.45 per cent., chromium 1.60 to 1.70, nickel from nothing to 1.80, manganese 0.60, silicon 0.25, aluminium 1, sulphur and phosphorus 0.025 each, and, in the latest type of alloy, molybdenum up to 0.25 per cent. The properties of the alloys are noted broadly, and the heat treatment before nitriding, the nitriding process, and the requisite equipment are described.

Characteristics of Nitralloy. (American Machinist, European Edition, 1928, Vol. 67, Jan. 14, p. 915).

Surface Hardening by Nitrogen. (Foundry Trade Journal, 1927, Vol. 37, Nov. 24, p. 135). A brief description is given of the Fry process of nitrogen case-hardening. The disadvantages and limitations of the process are pointed out.

The Cementation of Metals by Diffusion. G. Grube. (Zeitschrift für Metallkunde, 1927, Vol. 19, Nov., pp. 438-447). The author has made a systematic study of the diffusion of the metals iron-chromium, iron-aluminium, iron-tungsten, iron-molybdenum and nickel-chromium, and has calculated their coefficients of diffusion. The resistance of the cemented surfaces to chemical attack has been investigated, and test results are recorded.

Case-Hardening of Metals by Diffusion—Diffusion of Tungsten in Iron. G. Grube and R. Schreider. (Zeitschrift für anorganische und allgemeine Chemie, 1927, Vol. 168, Nov. 21, pp. 17-30).

The Cementation of Iron, Nickel, and Cobalt by Boron and Beryllium. I. Fetchenko-Tchopivski. (Communication from the College of Engineering, Warsaw, 1927). The researches are published in the form of five memoirs dealing respectively with the cementation of iron and steel with boron, the cementation of nickel and some special steels with boron, the cementation of iron and steel with beryllium, the

cementation of nickel and some special steels with beryllium, the cementation of cobalt with boron and beryllium.

Contribution to the Study of Metallic Cementations. J. Laissus. **Cementation of Ferrous Alloys by Boron.** (*Revue de Métallurgie, Mémoires*, 1927, Vol. 24, Oct., pp. 591-600). **Cementation of Ferrous Alloys by Titanium and Zirconium.** (Dec., pp. 764-775). **Cementation of Ferrous Alloys by Uranium.** (1928, Vol. 25, Jan., pp. 50-57). The continuation of an earlier series of articles (see *Journ. I. and S.I.*, 1927, No. II. pp. 575-576). In the present instalments the author discusses the iron-boron and iron-titanium diagrams, and describes the phenomena observed during the cementation of steel by boron, titanium, zirconium, and uranium. In all cases the thickness of the cemented zone increased with both time and temperature of cementation, but decreased as the carbon content of the steel increased. Titanium, zirconium, and uranium produced very hard cases, both before and after quenching; the boron case was fairly hard after quenching. Oxidation at 800° C. was relatively feeble with boron, titanium, and uranium, and very feeble with zirconium; above that temperature the resistance of the uranium case was superior to that of the untreated steel at the same temperatures. Boron and zirconium rendered the cases very resistant to attack by 50 per cent. hydrochloric acid; the titanium and uranium cases were, however, very easily soluble in that acid and also in sulphuric acid (33° Bé.), though the solubility of the titanium case in nitric acid (18° Bé.) was somewhat less, and that of the uranium case much less, than that of the uncemented steel. None of these metals gave cases resistant to rusting.

HEAT TREATMENT OF IRON AND STEEL.

Surface Decarburisation of Carbon Steel. E. H. Schulz and W. Hülsbruch. (*Archiv für das Eisenhüttenwesen*, 1927, Vol. 1, Sept., pp. 225-240; *abstracts*, *Stahl und Eisen*, 1927, Vol. 47, Oct. 13, pp. 1694-1695; *Metallurgist*, 1927, Nov. 25, pp. 164-165; *Journ. I. and S.I.*, 1927, No. II. p. 577).

Facts and Principles concerning Steel and Heat Treatment.—Part XVI. H. B. Knowlton. (*Transactions of the American Society for Steel Treating*, 1928, Vol. 13, Jan., pp. 142-154). This part begins a series of articles discussing case-hardening practice. The history and object of case-hardening are reviewed, and the selection of steels suitable for the process is discussed. Specifications are given for case-hardening steels, and normal and abnormal steels are briefly discussed.

Facts and Principles concerning Steel and Heat Treatment.—Part XVII. H. B. Knowlton. (Transactions of the American Society for Steel Treating, 1928, Vol. 13, May, pp. 848–880). An attempt is made to explain in simple language the mechanism of carburisation and the effect of different heat treatments following carburising. The article is illustrated with numerous diagrams and photomicrographs.

Study of the Penetration of the Quenching Effect in Projectiles. A. M. Portevin. (Extrait du Mémorial de l'Artillerie Française, Paris, 1927, pp. 103–166, with 23 plates). The penetration of the quenching effect depends upon a number of factors which may be grouped in three categories: (1) the chemical composition and initial condition; (2) the thickness and shape of the piece; (3) the temperature and time of heating, quenching temperature, and cooling medium. The first part of the Report consists of a study of the penetration of the quenching effect in quenched projectiles by means of plotting curves of penetration into the walls of the projectile after quenching and annealing. In the second part the influence of the penetration of the quenching effect on the mechanical properties of semi-hard steels and quenched and annealed steels is studied. The third part is a discussion of the results in relation to the heat treatment, the hydraulic test, and firing tests. The whole investigation relates to projectiles of calibres from 120 mm. upwards.

Quenching—A Practical Study on Rapid Cooling. P. J. Haler. (Mechanical Engineering, 1927, Vol. 49, Nov., pp. 1187–1191; Heat Treating and Forging, 1927, Vol. 13, Dec., pp. 490–494). The author deals with the subject of quenching generally, and describes his own experiments to determine the influence of the direction of plunging on the distortion produced. He discusses the stream-lines generated in the quenching medium as the quenched body is moved through it and their effect on the quenching phenomena.

The Water-Hardening of Tool Steels. A. Mumper. (Forging, Stamping, Heat Treating, 1927, Vol. 13, Nov., pp. 444–446). A practical heat-treater relates his experiences in handling steels of various descriptions, and offers suggestions for improving practice.

Progress in Hardening High-Speed Steel. R. M. Sandberg. (Fuels and Furnaces, 1928, Vol. 6, Jan., pp. 53–56). A brief discussion of the composition and heat treatment of high-speed steel.

What Happens When High-Speed Steel is Quenched? B. H. De Long and F. R. Palmer. (Transactions of the American Society for Steel Treating, 1928, Vol. 13, Mar., pp. 420–434). The authors deal with the metallography of high-speed steel when tempered at 1100° F. after quenching from various temperatures below 1300° F.

High-Temperature Quenching Treatment Applied to Cold Heading Ball Dies of Plain Carbon Steel. F. L. Wright. (Transactions of the American Society for Steel Treating, 1928, Vol. 13, Feb., pp. 282-296). The paper describes a high temperature quenching treatment for cold forming dies of plain carbon steel, and a submerged water spray quenching apparatus used for quenching double-end cold-heading dies. An increase in quenching temperature from 1470° to 1620° F. followed by a suitable tempering treatment has doubled the life of dies by increasing their fatigue resistance.

On a New Method of Quenching Steels in a High-Temperature Bath. K. Honda and K. Tamaru. (Transactions of the American Society for Steel Treating, 1928, Vol. 13, Jan., pp. 95-104, 125). The authors discuss the method of quenching steels in a hot quenching medium in order to obtain direct a troostitic or sorbitic structure without subsequent tempering. Mercury and a salt mixture (65 per cent. KNO_3 and 35 per cent. LiNO_3) were used as hot quenching media. Carbon steel (0.9 per cent. of carbon) was quenched in mercury below 150° C. and in the salt mixture above that temperature, and the hardness, tensile strength, elongation, and impact resistance were measured. Martensitic structure was obtained by quenching the specimens in the hot salt bath up to 200° C., troostitic structure in a range of 300° to 400° C., and sorbitic structure above 400° C. When the temperature of the bath is below 120° C. quenching cracks always form, above 150° C. any desired structure may be obtained without fear of quenching cracks. The mechanical properties of the steel submitted to hot quenching are not inferior to those quenched in water and then tempered.

New Theories on Tempering Steel. A. Heller. (American Machinist, European Edition, 1927, Vol. 67, Dec. 31, pp. 797-799; 1928, Vol. 67, Jan. 14, pp. 903-907; Jan. 28, pp. 971-974). The phenomena which take place in steel during heating, cooling, quenching, and tempering are discussed, and the development of such properties as hardness and brittleness are explained. Some of the views expressed are new, and are not entirely accepted by metallurgists. Further matters dealt with are types of commercial tool steels, volume changes due to hardening and tempering, causes of warping and bulging, variations in hardness due to tempering, the colour method of tempering steels, and the effect of time variations on the colour and hardness of the metal, temperature control by fusible alloys, proper drawing temperatures, &c.

Heat Treatment and Metallography of Steel. H. C. Knerr. (Forging, Stamping, Heat Treating, 1927, Vol. 13, Oct., pp. 420-421). The continuation of a series of articles (see Journ. I. and S.I., 1927, No. II. p. 584). The importance of the rate and degree of heating articles

in heat treatment is explained, and examples of the bad effects due to unequal, excessive, or too rapid heating are given.

Standardisation of Heat Treatment of Aeronautical Steels. L. Gazzaniga. (*Technique Moderne*, 1928, Vol. 20, Mar. 1, pp. 191-194).

Further Experiments on Annealing Mild Steel Sheets. J. C. Godsell. (Swansea Technical College Metallurgical Society, 1928, Feb. 18). In a previous paper (Mar. 1927) the author gave an account of some experiments carried out to show the influence of annealing temperature on the properties of both hot- and cold-rolled mild steel sheets, and the present paper gives the results of further experiments. The author has studied the effects of annealing at low temperatures on the Erichsen value of hot-rolled sheets, the influence of annealing temperature on the Erichsen value of hot- and cold-rolled sheets, and the influence of annealing temperature on the properties of mild steel sheets as shown by the alternating bend test.

Annealing of Hardened Steels, with Special Reference to Low Temperature. A. Merz and C. Pfannenschmidt. (*Zeitschrift für anorganische und allgemeine Chemie*, 1927, Vol. 167, Nov. 1, pp. 241-253). A summary of the work of other investigators.

Means for Improving Rail Material. Pilz. (*Stahl und Eisen*, 1927, Vol. 47, Oct. 6, pp. 1645-1651; *abstracts*, *Metallurgist*, 1927, Dec. 30, pp. 183-185; *Journ. I. and S.I.*, 1927, No. II. p. 582).

Patenting of Steel. J. S. G. Primrose. (Transactions of the American Society for Steel Treating, 1928, Vol. 13, Apr., pp. 617-637). The mechanism and purpose of patenting are explained, and the different forms of furnaces and heating used are described in detail. The different classes of steel commonly treated for particular purposes are described, and the general practice and methods of overcoming faults are discussed from the point of view of physical properties and the microstructure. Micrographical details are included of numerous wire specimens examined to ascertain the best methods of control to ensure satisfactory production of the highest quality of finished wire.

Heat Treatment of Steel Wire. J. D. Brunton. (*Wire*, 1928, Vol. 3, Jan.; pp. 10-12). British practice in annealing, normalising, and patenting before drawing is described.

Low-Carbon Bolts show Uniformly High Strength. E. F. Ross. (*Iron Trade Review*, 1927, Vol. 81, Oct. 27, pp. 1025-1027). A brief outline is given of the manufacture of low-carbon steel bolts, and a method of heat treatment is described in which the bolts are subjected

to a drastic quenching in a special solution resulting in a great increase in tensile strength of the steel. The solution consists of 30 parts of water and 1 part of soluble oil to which is added a very small amount of soda ash to assist in forming and maintaining an emulsion. The temperature of the quenching solution is maintained at between 120° and 140° F. The purpose of the solution is to give a lustrous black finish to the work.

Materials for and Heat Treatment of High-Duty Geared Wheels. A. Hofmann. (*Zeitschrift des Vereines deutscher Ingenieure*, 1928, Vol. 72, Feb. 25, pp. 259-264). The underlying differences in the use and heat treatment of alloy steels and "improved" steels are described, and the dependence of the precision of the wheels on the shape, working, and heat treatment of the material is pointed out. The various materials and heat treatments employed in the manufacture of German and American gears are described, as well as the various processes for reducing distortion during hardening and the precautions taken to protect those parts from the action of the cementation gases which have to be worked further after the hardening process has been completed.

The Rapid Normalising of Overstrained Steel. W. E. Woodward. (Paper read before the Iron and Steel Institute, May 1928: this *Journal*, p. 661).

Heat Stresses arising during Cooling or Treatment of Hollow Bored Cylinders. E. Maurer. (*Stahl und Eisen*, 1928, Vol. 48, Feb. 23, pp. 225-228). The progressive fall in temperature in cast hollow nickel-chromium steel cylinders, during cooling, has been studied, and the magnitude of the tangential stresses is the subject of a mathematical study. A diagram shows the temperature distribution in cooling quickly from the point of recalescence. The boring out of large cylinders prior to treatment greatly reduces the quenching stresses in the walls.

Metallurgical Theories for the Practical Iron and Steel Man. C. H. Plant. (*Iron and Steel Industry*, 1927, Vol. 1, Dec., pp. 85-86; 1928, Jan., pp. 113-114; Feb., pp. 159-160; Mar., pp. 193-194; May, pp. 250-252). The continuation of a series of simple and practical articles explaining the complex theories underlying the metallurgy of iron and steel (*see Journ. I. and S.I.*, 1927, No. II. p. 647). In the present numbers the author concludes his remarks on hardening and annealing, and deals briefly with case-hardening; he then sketches the theory of the constitution of cast iron. Attention is next turned to some of the properties of cast iron, and the influence of carbon and the form in which it occurs. The effects of impurities and of other elements purposely added to the cast iron are described. Alloy steels are next discussed.

WELDING.

Welding Chrome Iron and Steels. (Iron Age, 1928, Vol. 121, May 3, pp. 1242-1244). Factors to be observed in the welding of high-chromium steel are discussed. Difficulties in making a sound clean joint increase as the chromium content increases, as a result of the formation of infusible oxides, consisting chiefly of chromium oxide, together with smaller amounts of iron oxide, manganese oxide, and silica. Ordinary fluxes for welding or brazing are unsatisfactory. A special flux known as "Cromaloy flux" is recommended, but no particulars are included of its nature. The best results are obtained with a strictly neutral flame.

Electric Arc Welding with Alternating Current. P. Schmatz. (Röhrenindustrie, 1928, Vol. 21, Jan. 19, pp. 23-24; Feb. 16, pp. 89-91; Mar. 15, pp. 135-136). The author explains why direct current has so long held the field in arc welding processes, and shows that, nevertheless, alternating current may equally well be applied. He discusses the properties of the electric arc and the characteristics of alternating current as applied to arc welding, and describes the construction of transformers for use with a.c. arc welders. He finally deals with the electrodes used in arc welding, the making of the welds, and their properties.

Control in Pressure Vessel Welding. H. E. Rockefeller. (Paper read before the International Acetylene Association, Nov. 16-18, 1927; Heat-Treating and Forging, 1928, Vol. 14, Jan., pp. 34-37; Mechanical Engineering, 1928, Vol. 50, Feb., pp. 133-136). A description is given of the materials and methods used in manufacturing by welding pressure vessels 6 ft. in diameter and designed for a working pressure of 300 lb.

New Resistance Welding Machines. A. Hilpert. (Zeitschrift des Vereines deutscher Ingenieure, 1928, Vol. 72, Mar. 3, pp. 305-310). A variety of welding machines of different types are described and illustrated.

Electric Resistance Welding. A. Bidault des Chaumes. (Génie Civil, 1928, Vol. 92, Jan. 7, pp. 9-12). The author describes the principles involved and the apparatus used in electric resistance welding by the Thomson process.

Methods of Welding by Electricity. C. L. Ipsen. (Heat-Treating and Forging, 1928, Vol. 14, Mar., pp. 268-269).

The Autogenous Welding of Stainless Steels. H. Bull and L. Johnson. (Paper read before the British Acetylene and Welding

Association, Mar. 29, 1928: *abstract*, Engineering, 1928, Vol. 125, Apr. 20, p. 478). The authors describe the effects of welding upon the properties of stainless steel, and give notes on the actual application of the welding process to such steels.

Autogenous Welding, with Positive Equalisation of the Working Pressure and of the Gas Volumes. (Röhrenindustrie, 1927, Vol. 20, Nov. 10, pp. 349-351). The article describes an oxy-acetylene blow-pipe invented by F. Mangiameli, the purpose of which is to equalise the pressure and volumes of the two gases. The theory of its design and the reason for its need are explained.

Fusion Welding. W. Hoffmann. (Zeitschrift des Vereines deutscher Ingenieure, 1928, Vol. 72, Feb. 18, pp. 215-218).

A Socket Welding Mill. G. B. Werner. (Röhrenindustrie, 1928, Vol. 21, Feb. 2, pp. 67-69). The manufacture of welded sockets, the material used, and the furnaces and mills employed, are described.

Welding Steel Castings. L. E. Everett. (Paper read before the International Acetylene Association, Nov. 1927: Foundry, 1927, Vol. 55, Nov. 15, pp. 898-899). A discussion of the factors to be considered in the selection of a welding process for the repair of steel castings, which depends largely on the nature of the defect and type of casting.

What are the Justifiable Uses of Welding in Production of Steel Castings? R. A. Bull. (Iron Trade Review, 1927, Vol. 81, Dec. 15, pp. 1475-1477, 1488; Foundry, 1928, Vol. 56, Jan. 15, pp. 48-50).

Present Position and Application of Welding Cast Iron. W. Zimm. (Giesserei-Zeitung, 1927, Vol. 24, Oct. 15, pp. 561-566). The author reviews the various welding methods from the point of view of their metallurgical effect on the structure of grey cast iron. In this respect and for ease of application the electric welding of the parts in the cold, using special cast alloy electrodes, appears to be the most suitable for avoiding injury to the cast metal.

Welding of Cast Iron. Bardtke. (Giesserei-Zeitung, 1927, Vol. 24, Sept. 15, pp. 505-515). The author illustrates numerous examples of the use of welding for the repair of castings.

Bronze Joints in Cast-Iron Pipe. T. C. Fetherston. (Iron Age, 1927, Vol. 120, Dec. 29, pp. 1782-1784). In discussing bronze-welded pipe the author points out the weakening effect of the collar type of weld on the pipe. He further shows that with a new design of shear V-joint breakages are practically eliminated.

Bronze Welding Cast-Iron Pipe by Back-Stepping Method. H. Y. Carson. (Paper read before the American Waterworks Association, June 1927 : *Iron Trade Review*, 1928, Vol. 82, Jan. 12, pp. 138-139). The procedure to be followed in the bronze-welding of cast-iron pipe is discussed.

Economical Oxy-Acetylene Cutting Needs Intelligent Supervision. J. L. Anderson. (Paper read before the American Welding Society, Nov. 21, 1927 : *Iron Trade Review*, 1927, Vol. 81, Dec. 8, pp. 1421-1423, 1428 ; *Foundry*, 1928, Vol. 56, Mar. 1, pp. 187-190). The author discusses a number of factors involved in the economical cutting of metals.

MISCELLANEOUS PRODUCTS.

Wire Ropes in Mines : Some Notes Regarding their Manufacture and Use. (Mines Department : Safety in Mines Research Board Paper No. 41, 1928). The first part of the paper is devoted to an account of the manufacture and properties of wire used and of the construction of the rope itself, and also includes a section which deals at length with the manufacture of steel generally. The remainder of the paper deals with the selection and use of wire ropes under mining conditions. There are chapters on the factor of safety, the various types of capping, the renewing of the capping, lubrication, the drum, the handling and care of a rope, the examination of ropes in use, and the deterioration of ropes in service. Guide ropes, balance ropes, and haulage ropes are considered, as well as winding ropes. A list is also given of the more urgent outstanding problems in regard to which research is in progress.

Modern Methods in the American Tube-Making Industry. E. Baumann. (*Stahl und Eisen*, 1928, Vol. 48, Feb. 2, pp. 135-138). Screw-cutting machines of modern type are illustrated and described. The machines can be set to cut taper or parallel threads on pipes or in sockets as desired.

Development of High-Speed Steel Hack-Saws or Cutting-Off Saws. H. B. Allen. (*Transactions of the American Society for Steel Treating*, 1928, Vol. 13, Apr., pp. 603-616). The author discusses the application of high-speed steel to hack-saw blades. The blades are made from blanks sheared from annealed hot-rolled steel sheet of the following typical composition : C 0.65, Cr 3.80, W 18.5, V 1.0 per cent. The blades are heated to a temperature of about 1700° to 1750° F. and quenched in oil. The steel remains plastic for some time after hardening, and does not attain its full hardness for a considerable time after becoming quite cold. The relative performance of saws made of high-speed steel and low tungsten steel is also shown.

Cutting Tools with Welded Tips of High-Speed Steel. C. W. Drescher. (Maschinenbau, 1928, Vol. 7, Jan. 19, pp. 49-55).

The Construction of High-Pressure Boiler Shells. (Génie Civil, 1928, Vol. 92, Apr. 21, pp. 392-393). The welding method of manufacturing high-pressure boiler shells adopted by the Thyssen Company at Mülheim/Ruhr is briefly described.

Electrically Operated Boiler Shell-Plate Bending Machine. Weil. (Machinery, 1927, Vol. 31, Nov. 24, pp. 247-250). The design of the machines illustrated and described in this article embodies the fundamental features of existing machines, which consist mainly of an arrangement of three heavy vertical beams of which the outer two are fixed while the central one performs the bending operation. The whole driving mechanism, consisting of motor and gearing, is carried by one of the fixed beams.

Mild Steel Fireboxes for Locomotives. H. Bleibtreu. (Archiv für das Eisenhüttenwesen, 1928, Vol. 1, Mar., pp. 571-581). In America mild steel plates have been used for over 40 years for the construction of locomotive fireboxes, whereas in Europe copper continues in use down to the present day. During the war steel fireboxes were brought into use in Germany, but experience with them was not satisfactory, and they were afterwards replaced by copper boxes. The material used was acid open-hearth steel of 23 to 28 tons per sq. in. tensile strength, with an elongation of 25 per cent. Failure was chiefly due to the following causes: (1) Local formation of coarse crystalline structure on both the fire and water sides of the plate; (2) bulges due to blowholes which did not weld up in rolling and to segregation; (3) cracks around the stay-bolt holes; (4) cracks radiating from the rivet holes; (5) local corrosion. Similar defects have been noted in American steel fireboxes, but greater care is taken in designing the latter to allow for elastic play in heating and cooling. The conditions laid down for the manufacture of American steel fireboxes are quoted, and their design in general and in detail is well illustrated.

Sheet Working Machines. R. Wittlinger. (Zeitschrift des Vereines deutscher Ingenieure, 1928, Vol. 72, Feb. 25, pp. 249-253). A variety of machines for working plates and sheets are described and illustrated.

The Steel-Wool Industry. C. Field. (Paper read before the American Society of Mechanical Engineers, Dec. 5-8, 1927: Mechanical Engineering, 1927, Vol. 49, Dec., pp. 1315-1321). A brief description of the industry, its art, extent, and recent development, is given, followed by particulars of a fully automatic and continuous machine for manufacturing steel wool.

Steel Wool—How it is Made. (Iron Age, 1927, Vol. 120, Dec. 22, pp. 1728–1729, 1765). An illustrated account of the methods and machinery used in the manufacture of steel wool.

PICKLING.

Practical Features of Pickling. W. G. Imhoff. (Iron Trade Review, 1927, Vol. 81, Oct. 27, pp. 1021–1024; Nov. 10, pp. 1162–1163; Nov. 24, pp. 1291–1293; Dec. 8, pp. 1418–1420; Dec. 22, pp. 1539–1542; 1928, Vol. 82, Jan. 19, pp. 202–205; Feb. 2, pp. 318–320; Feb. 16, pp. 443–445; Mar. 1, pp. 557–559, 565; Mar. 15, pp. 677–679, 684; Mar. 29, pp. 804–806; Apr. 12, pp. 943–945, 978; Apr. 26, pp. 1069–1071). A comprehensive series of articles discussing various problems encountered in the pickling of iron and steel.

Disposal of Acid-Iron Wastes from a Steel Mill. S. E. Coburn. (Industrial and Engineering Chemistry, 1928, Vol. 20, Mar., pp. 248–249). The author considers the problem of disposing of the waste liquors of the pickling process. The following methods are briefly dealt with: (1) Dilution with water and discharge into sewers; (2) neutralisation with lime and discharge into sewers; (3) treatment with lime in separate tanks and disposal of sludge; (4) disposal by cesspool method; (5) recovery of ferrous sulphate.

COATING OF METALS.

Parkerisation. J. Cournot. (Bulletin de la Société des Ingénieurs Civils de France, 1927, Vol. 80, Sept.–Oct., pp. 1071–1080). The Parker process for protecting iron and its alloys against corrosion is outlined, and test results to show its efficiency are reported. The pieces to be coated are dipped for an hour or more in a hot, strong solution of complex phosphates of iron and manganese; the composition of the bath is not stated. The resulting coat is corrosion-resisting and may be given various finishes, or it may be painted, lacquered, varnished, or enamelled.

The Theory of Chromium Plating. E. A. Ollard. (Paper read before the Electroplaters' and Depositors' Technical Society, Nov. 9, 1927: Electrical Review, 1927, Vol. 101, Nov. 25, p. 928; Metal Industry, 1927, Vol. 31, Nov. 11, pp. 437–439; Nov. 18, pp. 461–462). The author first reviewed the existing three theories and pointed out in what particulars they failed to hold good. He next discussed the

constituents of the plating bath, the presence of which were known to be necessary for deposition to occur, and evolved a new theory to explain the working of the bath.

Electrodeposition of Chromium. J. G. Roberts. (The Royal Technical College Metallurgical Club Journal, 1927-28, No. 6, pp. 19-22). The work of different investigators is reviewed.

Influence of the Cathode on the Electrodeposition of Chromium. H. S. Lukens. (Paper read before the American Electrochemical Society, Apr., 1928). The production of passive nickel by electro-deposition is reported. The influence of passive nickel, of active nickel, copper, and lead on the composition of solutions for the electro-deposition of chromium is studied and the results are discussed. Means for correcting the chromic salt and sulphuric acid content of solutions for the deposition of chromium are indicated.

Behaviour of Plating Baths and Anodes during Electro-Deposition of Chromium. R. Schneidewind and S. F. Urban. (Paper read before the American Electrochemical Society, Apr. 1928). In a study of the behaviour of chromic acid plating baths during electrolysis, the authors place emphasis upon the relationship between anodes and the solution composition. If all plating conditions are kept constant, trivalent chromium in the bath approaches an equilibrium concentration, a condition of steady state. The magnitude of this concentration is a function of the following conditions: anode current density, the nature of the anode material, the temperature of the bath, and the sulphate concentration of the bath. Where iron anodes were used they dissolved at a constant rate during electrolysis. The solubility is also affected by the above conditions. Lead is less soluble at low temperatures, but proved even more soluble at high temperatures than iron. Dissolved iron and trivalent chromium greatly contract the range of current densities at which good plate is produced.

The Effect of Trivalent Chromium and Iron on Chromic Acid Chromium Plating Baths. R. Schneidewind, S. F. Urban, and R. C. Adams, jun. (Paper read before the American Electrochemical Society, Apr. 1928). The authors have found that the current efficiency of chromium deposition from chromic acid baths is a straight-line function of the logarithm of the current density. The slope and position of this line are affected by the temperature and composition of the bath. In baths containing chromic acid and sulphate ion, bright deposits having a thickness of 0.0007 mm. (0.00003 in.) or less are obtained on copper between limits corresponding roughly to 5 per cent. and 20 per cent. current efficiencies. In cases of other metals the range of current efficiencies yielding bright plate may be narrower. Heavy deposits on all metals are best obtained at 12 to 14 per cent. current efficiency.

Other things being equal, increasing the concentration of trivalent chromium and iron does not appreciably change the relationship of current density to current efficiency. However, the range of current densities producing bright plate is markedly contracted.

Notes on the Hardness and Structure of Deposited Chromium. L. E. Grant and L. F. Grant. (Paper read before the American Electrochemical Society, Apr. 30, 1928). The authors have investigated the effect of current density and temperature on the hardness of chromium deposits. The hardest deposits were obtained at relatively high current densities. The occurrence of a network of cracks was observed in some deposits. The significance of this condition in relation to corrosion resistance is discussed.

Protective Value of Chromium Plate. E. M. Baker and W. L. Pinner. (Journal of the Society of Automotive Engineers, 1928, Vol. 22, Mar., pp. 331-334). The protection afforded by electro-deposited coatings of chromium alone and in combination with nickel and copper is discussed. The use of chromium by itself has little protective value for outside exposure.

Chromium as a Corrosion Preventative. L. Wright. (Paper read before the Electroplaters' and Depositors' Technical Society, Dec. 21, 1927: Metal Industry, 1927, Vol. 31, Dec. 23, pp. 577-579; 1928, Vol. 32, Jan. 6, p. 8). The ways in which chromium deposits may fail, their appearance, and the author's opinion as to the causes, are described.

Progress in Chromium Plating. W. Pfannhauser. (Korrosion und Metallschutz, 1927, Vol. 3, Nov., pp. 247-248).

The Present-Day Position of Chromium Plating. E. Liebreich. (Korrosion und Metallschutz, 1928, Vol. 4, Feb., pp. 29-32).

Chromium Plating. E. J. Dobbs. (Paper read before the Institution of Production Engineers: Automobile Engineer, 1928, Vol. 18, Jan., pp. 15-16). An outline of present-day practice.

Applying Chromium Plating for Appearance and Wear. F. W. Curtis. (American Machinist, European Edition, 1928, Vol. 68, Mar. 17, pp. 241-244).

Chromium-Plating Patents. R. Schneidewind. (University of Michigan, Department of Engineering Research, Engineering Research Bulletin No. 8, Nov. 1927; Metal Industry, 1928, Vol. 32, Jan. 20, pp. 89-92; Feb. 3, p. 140).

Common Defects in Nickel Deposits. D. J. Macnaughtan. (Paper read before the Electroplaters' and Depositors' Technical Society, Mar. 21, 1928: *Metal Industry*, 1928, Vol. 32, Mar. 30, pp. 326-327, 331).

Nickel Plating. J. Galibourg. (*Revue de Métallurgie, Mémoires*, 1927, Vol. 24, Nov., pp. 660-669). Methods of nickel-plating and the solutions used are described. The ferricyanide, the salt spray, the intermittent immersion, and the air exposure tests are briefly noted. Results are given of tests carried out in France on the American formulæ.

Cadmium Deposits as Rust Protection. W. Pfanhauser. (*Korrosion und Metallschutz*, 1928, Vol. 4, Mar., pp. 58-59). The rust-protection properties of electrolytically deposited cadmium are compared with those of other metals, such as zinc, nickel, &c. Some reference is also made to the conditions under which cadmium can be deposited.

Metallic Coatings. M. Schlötter. (*Korrosion und Metallschutz*, 1928, Vol. 4, Apr., pp. 74-82). The author first discusses the pickling process and the mechanism of the removal of oxide from the surface of the object to be coated. He then considers some of the phenomena occurring in various methods of coating and some of the problems to which they give rise; among the processes dealt with are galvanising, tin plating, sherardising, the Schoop process, lead coating, and the electrolytic deposition of various metals.

Design of Galvanising Furnaces. M. Epstein. (*Iron Age*, 1928, Vol. 121, Apr. 26, pp. 1151-1152). The design of a successful galvanising furnace should be such that the outside chamber of the pot is kept as low as possible and that little or no heat should be transferred into the pot below the dross line. The usual design of coke-fired furnaces gives no protection to the pot, and it has been found that pots fired with coke do not last very long and much greater amounts of dross are produced. The relative values of gas, coke, and oil as fuel for galvanising furnaces are shown.

Coating by Molten-Metal Spraying. (*Machinery*, 1928, Vol. 31, Jan. 19, pp. 505-510). The "metalayer" process is described, and some of its many uses are illustrated. The metal to be deposited is fed into a "pistol" as wire; it is melted by a small oxy-acetylene flame, and is then blown on to the object to be coated by compressed air. The coating cannot be separated from the object by severe hammering or bending, and oxidation is prevented by using a reducing flame in the pistol.

Recent Developments in Metal Spraying. R. A. Parkes. (Metal Industry, 1928, Vol. 32, Feb. 24, pp. 201-203; Mar. 9, pp. 249-251; Mar. 16, pp. 273-274). The latest apparatus for metal spraying is described, and the properties and characteristics of the coatings in various metals are discussed.

The Ferro-Wet Process of Vitreous Porcelain Enamelling. W. Marshall. (Foundry Trade Journal, 1927, Vol. 37, Nov. 17, p. 124; Dec. 22, p. 216). A brief discussion of a number of the factors involved in the production and design of castings intended to be enamelled by the wet enamelling process.

Enamelling Metals with the Aid of Automatically Controlled Conveyors. (Iron Age, 1928, Vol. 121, Jan. 26, pp. 264-267). Practice at the new plant of the Louisville Enamel Products Co., Louisville, Kentucky, for the enamelling of metals is illustrated and described. The layout of the plant is also shown.

Improved Enamelling Process. F. W. Manker. (Iron Trade Review, 1928, Vol. 82, Mar. 8, pp. 619-621, 623). The methods and equipment of the American Stove Co. for the enamelling of stoves are described and illustrated. Continuous automatic gas-fired enamelling furnaces are in operation.

Controlling the Consistency of Enamel Slips. W. N. Harrison. (United States Bureau of Standards, 1927, Technologic Paper No. 356). The purpose of the work described was to study vitreous enamel slips in order to develop adequate means for measuring and controlling their consistency under plant conditions.

Modern Types of Japanning Ovens. W. J. Miskella. (Fuels and Furnaces, 1928, Vol. 6, Jan., pp. 77-80). The author briefly discusses the latest types of steam, gas, oil, and electrically heated japanning ovens.

Operation of Japanning Oven Burners. W. J. Miskella. (Fuels and Furnaces, 1928, Vol. 6, Feb., pp. 225-226, 264). A brief discussion of the various types of burners used in heating japanning ovens, their adjustment, operation, and maintenance.

Temperature Control in Japanning Ovens. W. J. Miskella. (Fuels and Furnaces, 1928, Vol. 6, Mar., pp. 361-364). The construction and use of various instruments for measuring the temperature of japanning ovens are briefly discussed.

Measuring the Fuel Consumption of Japanning Ovens. W. J. Miskella. (Fuels and Furnaces, 1928, Vol. 6, Apr., pp. 507-509).

A brief discussion of the construction and operating features of gas meters as applied to japanning ovens.

Planning an Enamelling Shop for High-Quality Work. P. B. McBride. (Iron Trade Review, 1927, Vol. 81, Nov. 24, pp. 1287-1289). A brief discussion of the problems to be considered in the design and construction of an enamelling plant. The arrangement of sand-blast, pickling, milling, dipping, spraying, drying, and other equipment requires special care if the enamelling operations are to be carried out efficiently.

Protective Paint from Rubber. H. Gray. (Industrial and Engineering Chemistry, 1928, Vol. 20, Feb., pp. 156-158). A protective paint has been prepared from rubber, which it is claimed can be used commercially. The chief features of the new paint are: (1) Good adhesion to metals; (2) resistance to acids, alkalies, corrosive gases, and corrosive chemicals in general; (3) low permeability to moisture, salt solutions, salt spray, &c.; (4) the film is tough and can be bent without injury; (5) the film does not flake when cut, and rust spreads very slowly from an exposed area.

PHYSICAL AND CHEMICAL PROPERTIES.

PROPERTIES AND TESTS OF CAST IRON.

Recent Developments in Cast Iron. J. G. Pearce. (Metallurgist, 1928, Feb. 24, pp. 25-26; Mar. 30, pp. 39-42). The author first discusses problems connected with the testing of cast iron, properties of the metal, and attempts that have been made to correlate the properties with the structure and composition. He then describes the hot-mould process, giving details of the composition of the iron, mould temperatures, &c., with complete test results on three specimens. Low-carbon iron and its production are next discussed. As the phosphorus in this material is invariably kept low, fluidity is attained by suitably increasing the silicon content. In Germany the low carbon is attained by the use of steel scrap in the cupola charge, while an American process employs a carbon-free silicide, such as calcium silicide, to render a white or mottled iron grey. The last section of the articles deals with chilled irons, which, owing to their silicon content, become grey and machinable on chilling. This metal has a small grain-size and resists fluid pressures well.

The Test-Bar Problem and Some Recent Developments. J. G. Pearce. (Paper read before the Institute of British Foundrymen: Foundry Trade Journal, 1928, Vol. 38, Mar. 22, pp. 201-203). The author first discusses the shape of cast-iron test-bars and advocates the use of square bars. The use of cast-on bars is not recommended owing to the many factors influencing the results of tests, the logical procedure being to cast a bar from the same metal at the same time as the casting proper, but in a separate mould. The exigencies of standard testing procedure do not permit a large number of bars, but in the British Engineering Standards Association specification at least three are recommended. It is not satisfactory to cast bars less than 0.875 in. thick, and this diameter is taken as representing castings up to $\frac{3}{4}$ in. across the main section. The largest bar recommended is 2.2 in. diameter to represent castings whose main section exceeds 2 in. Castings whose main section varies between $\frac{3}{4}$ and 2 in. are represented by a bar 1.2 in. diameter. The author also considers the respective merits and demerits of the tensile and transverse test. Certain difficulties of transverse testing might be overcome if the results were expressed as modulus of rupture instead of breaking load. The shear test is quite suitable for cast iron, but inconvenient and expensive

compared with other tests available. The objection to the Frémont test lies mainly in the fact that a too small bar is used.

The Variable Results of the Bending Test as Applied to the Testing of Cast Iron. F. Roll. (Giesserei-Zeitung, 1928, Vol. 25, Feb. 15, pp. 114-119). The transverse test of cast iron does not give approximately regular results as in the case of tensile tests on steel, the properties being affected by small differences in chemical composition, cooling conditions, and structure. The causes of the variations are discussed, and an endeavour is made to correlate them.

Mechanical Tests of Cast Iron. A. Portevin. (Lecture before the Swiss Association for the Testing of Materials, Dec. 1926; Report No. 3). A general review of the properties, constitution, and structure of cast iron, and of the methods of testing the physical and mechanical properties.

The Resistance to Wear of Cast Iron containing Phosphorus. E. Piowowsky. (Die Giesserei, 1927, Vol. 14, Oct. 22, pp. 743-747). The author presents the results of tests which show that the wear resistance of cast iron increases with increasing phosphorus content.

The Resistance to Wear of Cast Iron containing Phosphorus. (Foundry Trade Journal, 1928, Vol. 38, Jan. 12, pp. 25-26). This article is based on the above paper by E. Piowowsky.

The Wear of Cast Iron and its Relation to the Structure and Mechanical Properties. Kühnel. (Giesserei-Zeitung, 1927, Vol. 24, Oct. 1, pp. 533-541).

The Fatigue of Cast Iron. C. H. Bulleid and A. R. Almond. (Engineering, 1927, Vol. 124, Dec. 23, p. 827). Data on two more cast irons are given to supplement the information contained in an earlier paper by the first-named author. (See Journ. I. and S.I., 1927, No. I. p. 922.)

The Properties of Cast Iron at Low Temperatures, with Particular Reference to Cast-Iron Pipes and Tubes. C. Pardun and E. Vierhaus. (Die Giesserei, 1928, Vol. 15, Feb. 3, pp. 99-102; *abstract*, Foundry Trade Journal, 1928, Vol. 38, Apr. 26, p. 298). Experiments were carried out to determine what variations, if any, occurred in cast iron at low temperatures, such as are experienced during winter time in Europe. It was found that the mechanical properties of cast iron suffered no loss at such temperatures, noteworthy changes only occurring when the temperature dropped to -80°C . The cause of breakages to cast-iron pieces in winter must be attributed to stresses set up by

shrinkage, or, in the case of pipe systems, to the action of the frozen earth in which they are embedded.

High-Grade Cast Iron. J. E. Hurst. (Foundry Trade Journal, 1928, Vol. 38, Mar. 29, pp. 226-228). The author reviews the progress made in the improvement of the properties of high-duty cast iron. The strength properties, structural composition, thermal conditions, low total carbon content, and impact resistance are considered, and a table is included showing the chemical composition of typical irons. Cast iron for high-duty conditions should contain the lowest silicon content and total carbon content, and the highest combined carbon content compatible with commercial machinability and soundness of the castings. If high impact resistance is desired, it is advisable to reduce the phosphorus content. The graphite-size, and grain-size independently of the graphite-size, should be obtained in the smallest possible form. The use of certain alloy additions will be principally determined by commercial considerations.

High Tensile Cast Iron. A. Portevin. (Bulletin de l'Association Technique de Fonderie, July 1927. Reprint, pp. 1-15). The author discusses the influence of the various elements and the casting conditions and rate of cooling on the strength of cast iron. By proper control of all these factors castings of a tensile strength of 30 up to 40 kg. per sq. mm. can be obtained.

Present Status of Pearlitic Iron. R. Moldenke. (Iron Age, 1928, Vol. 121, May 3, pp. 1241). The author reviews the present status of pearlitic cast iron, and discusses its advantages and disadvantages. When highly superheated in melting and not oxidised, with gatings and risers properly placed, the iron is fairly fine-grained and dense. It is strong, and has excellent wearing qualities. The disadvantages are that it is not easy to produce without much experience with low-silicon cupola mixtures. Extra care is required with pattern equipment, gates, and risers. It is necessary to install mould-heating ovens allowing high-temperature operation and flexibility of operation for pouring off. The author is of opinion that the production of pearlitic cast iron should be carried out in a building quite apart from that used for other foundry operations, to avoid accidental use of the wrong mixtures and other mistakes.

Castings of High Resistance (Pearlitic Cast Iron). A. Le Thomas. (Revue Industrielle, 1928, Vol. 58, Jan., pp. 16-20). The manufacture, properties, and testing of pearlitic cast iron are described.

Development of Pearlitic Cast Iron. G. Meyersberg. (Zeitschrift des Vereines deutscher Ingenieure, 1927, Vol. 71, Oct. 8, pp. 1427-1432). A discussion on the strength and other properties of pearlitic cast iron.

Perlit Iron for Heat Engines. G. Meyersberg. (Archiv für Wärme-wirtschaft, 1927, Vol. 8, Nov., pp. 340-341). The author deals with the mechanical properties of pearlitic cast iron, with special reference to its resistance to high temperatures.

Mechanical and Physical Properties of High-Grade Grey Cast Iron, and Principles Underlying its Production. E. Zimmermann. (Zeitschrift für die gesamte Giessereipraxis, 1928, Vol. 49, Jan. 1, pp. 2-4; Jan. 8, pp. 17-18; Jan. 15, pp. 28-29; Jan. 22, pp. 38-39; Jan. 29, pp. 48-49; Feb. 5, pp. 54-56; Feb. 12, pp. 64-69; Feb. 19, pp. 71-72; Feb. 26, pp. 78-80; Mar. 4, pp. 91-93).

The Mechanical Properties of Grey Cast Iron in Relation to Structure and Treatment. K. von Kerpely. (Giesserei-Zeitung, 1928, Vol. 25, Jan. 15, pp. 37-49). The influence of the cross-section on the structure, of the rate of cooling, of the various alloying elements on the strength properties, of the casting temperature, and many other points, are discussed. The results of a variety of researches are reviewed, and other matters, such as heat treatment, superheated cast iron, &c., are dealt with. The various processes for the production of high-duty cast iron are critically compared.

The Structural Composition of Cast Iron by Weight and Volume. W. E. Dennison. (Foundry Trade Journal, 1928, Vol. 38, Mar. 29, pp. 224-225, 230). A method is described of selectively computing, from the usual ultimate analysis of cast iron, the structural composition by weight and volume, and the structural and volumetric compositions of various cast irons are tabulated.

Effect of Chemical Composition on the Structural Volume Analysis of High-Duty Cast Irons. J. L. Francis. (Iron and Steel Industry, 1927, Vol. 1, Dec., pp. 87-89). As a "standard" cast iron for high-duty purposes the following composition is taken :

	%
Combined carbon	0.9
Graphitic carbon	2.1
Silicon	1.0
Sulphur	0.1
Phosphorus	0.2
Manganese	1.0

The structural volume analysis of this iron is :

	%
Manganese sulphide	0.5
Iron-carbon-phosphorus eutectic	2.9
Graphite	6.9
Iron silicide	3.6
Pearlite	85.7
Cementite	0.3

The effects of alterations of the amounts of each element present are discussed, and a table is presented showing approximately quantitatively by what amounts the structural volume analysis is altered by 0.1 per cent. variation in the content of each element. Finally, a simple calculation is explained by which it is easily decided whether a cast-iron casting of a composition somewhat different from the "standard" has developed the maximum pearlitic matrix possible, the condition which is, of course, desired in a high-duty cast iron.

A Contribution to the Knowledge of Graphite in Grey Cast Iron and its Influence on the Strength. P. Bardenheuer and K. Ludwig. (*Die Giesserei*, 1928, Vol. 15, Apr. 20, pp. 354-365; Apr. 27, pp. 385-397).

On the Subject of Heredity in Cast Irons. B. Buffet and H. Thyssen. (*Revue Universelle des Mines*, 1928, Vol. 18, Apr. 1, pp. 5-7). On adding a proportion of hot iron to a mixture which had proved satisfactory the number of rejects increased, despite the fact that the analysis, temperature, and all other conditions were maintained the same as before. Coarse crystalline plates of graphite were found in the rejected pieces, and investigation showed them to be present in the hot iron. From these facts it is assumed that graphite is much less soluble than was thought, and could pass through the cupola intact. The coarse plates occurred in colonies, which served as starting-points for the development of fractures. The authors believe that the improvement of cast irons, either by jolting or by superheating, is due simply to the better solution of the graphite obtained by these methods. They consider that the classification of pigs by simple analysis is quite illogical, and that differentiation according to the appearance of the fracture is not so illogical as it appears; the ideal classification would take account of both aspects. The silicon in the final mixture referred to above was high, and the authors think that the same effects might not have occurred had the silicon been lower.

Grey Cast Iron in the Construction of Automobiles and Aircraft. G. Meyersberg. (*Die Giesserei*, 1927, Vol. 14, Oct. 22, pp. 747-750). The author discusses the improvements made in the properties of grey cast iron, and points out the suitability of this material for automobile and aircraft construction.

The Use of Cast Iron and Cast Steel in the Construction of Electrical Machinery. L. Schmid. (*Die Giesserei*, 1927, Vol. 14, Oct. 22, pp. 750-757; Oct. 29, pp. 770-775). The special requirements of grey iron and steel castings used in the construction of electric machines and steam turbines are discussed.

Cast Iron as Railway Construction Material. K. Sipp. (*Die Giesserei*, 1927, Vol. 14, Nov. 5, pp. 781-784). The requirements of

castings employed in railway construction and machinery are critically considered.

Special Cast Iron for Diesel Engines. B. Schulz. (Motorwagen, 1927, Vol. 30, Oct. 20, pp. 625-628). The author discusses the composition and properties of special cast irons developed in Germany and Switzerland.

Grey Iron and Silicon Iron for Agricultural Machinery. H. Jungbluth. (Kruppsche Monatshefte, 1927, Vol. 8, Dec., pp. 193-203; Die Giesserei, 1927, Vol. 14, Nov. 12, pp. 799-805). The properties of cast iron and high silicon iron, and their use for the manufacture of agricultural machinery, are described and discussed.

Intricate Spun-Sorbitic Castings. J. E. Hurst. (Iron Age, 1928, Vol. 121, Apr. 12, pp. 1007-1008). Typical composition and tensile strength are shown of piston valve liners made by the Hurst-Ball centrifugal casting process.

Cast Iron as an Engineering Material. T. Geilenkirchen. (Die Giesserei, 1927, Vol. 14, Oct. 22, pp. 721-724). A discussion of the development and importance of cast iron as an engineering material.

The Influence of Nickel in Iron-Carbon-Silicon Alloys containing Phosphorus. A. B. Everest and D. Hanson. (Paper read before the Iron and Steel Institute, May 1928: this Journal, p. 339).

Nickel in Cast Iron. A. B. Everest. (Paper read before the Institute of British Foundrymen: Foundry Trade Journal, 1928, Vol. 38, Apr. 12, pp. 255-258). The development of cast iron in general, and of nickel cast iron in particular, is briefly outlined. Commercial nickel cast irons may be divided into those having high and low nickel contents; those of intermediate content have little or no industrial application. Irons of low nickel content only are dealt with in the paper. Methods of adding nickel to cast iron are reviewed. The influence of nickel on various ordinary foundry mixtures is demonstrated and discussed. It is shown that in a mixture in which the total carbon and silicon contents are correctly balanced, and other elements are present in suitable proportions for a certain casting, the addition of nickel produces little improvement in strength properties, but has a definite advantage in reducing the tendency of the iron to chill. Nickel is known to act fundamentally as a graphitising agent in cast iron, consequently it would seem reasonable to expect that, in order to obtain the maximum benefit from nickel additions, the other principal graphitising agent in cast iron, namely, silicon, should be lowered. As the result of crucible experiments, it is shown that strength properties far in excess

of those normally associated with cast iron are obtained by the replacement of some of the silicon by nickel in suitable proportions. It is usually found for these purposes that two or three parts of nickel replace one of silicon in ordinary mixtures. Some results are also given from work at present in hand, on nickel cast iron made from cupola-melted low-silicon bases under ordinary foundry conditions. It is shown that such iron may have remarkably good properties.

Nickel in Castings of Iron and Steel. J. Galibourg. (*Revue de Métallurgie, Mémoires*, 1927, Vol. 24, Dec., pp. 730-739). The author discusses the effects on the structure of the addition of nickel to cast iron and cast steel, and shows how the physical properties of the resulting castings are improved. Nickel-chrome additions are also dealt with.

Improving Grey Cast Iron with Nickel. (Iron and Steel of Canada, 1927, Vol. 10, Oct., pp. 304-311). The effect of nickel in improving the machinability, increasing the "machinable hardness," strength, and wear resistance, eliminating porosity and internal shrinkage, and reducing and regulating chill of cast iron is described. The manner of making the nickel additions is also dealt with.

The Economic Value of Nickel and Chromium in Grey-Iron Castings. D. M. Houston. (*Transactions of the American Society for Steel Treating*, 1928, Vol. 13, Jan., pp. 105-125). The effects of nickel and chromium on the structure of cast iron are shown by means of photomicrographs. In making use of nickel and chromium in foundry mixtures, the author gives approximate equivalents to assist in determining the nature of the structure that may be obtained from an alloy mixture compared with one of plain iron or semi-steel. These approximate equivalents are as follows: One point of carbon equals 3 points of silicon, or 6 points of nickel, or 3 points of chromium in reducing chill. One point of silicon equals 2 points of nickel in reducing chill and neutralises 1 point of chromium. The practical applications of nickel-chromium grey iron are described, and the following examples cited: (a) Heavy section and pressure work; (b) Diesel engine liners, where uniform hardness is essential; (c) forming dies, jigs, and tool fixtures; (d) automobile cylinders. The importance of base composition as an economic factor is dwelt upon at length, and illustrations are given of nickel-chromium mixtures developed with a proper base composition, whereby the Brinell hardness was uniformly increased without impairing machinability at approximately the same cost per pound as plain cast iron.

Determines Properties of High-Silicon Irons. R. H. Holbrock. (*Foundry*, 1928, Vol. 56, Jan. 15, pp. 55-59). The author has examined the influence of silicon on the properties of grey cast iron. It is con-

cluded that the introduction of large amounts of silicon greatly decreases the strength of grey cast iron. In general, the hardness and specific gravity also are decreased with increasing silicon content. However, the hardness is a periodic function of the silicon content, and in some cases an increase in silicon causes an increase in hardness. When the silicon content is not in excess of 10 to 14 per cent., the metal is still strong enough to be useful for many purposes. The greatest change in the physical properties is occasioned by changing all of the carbon to the graphitic form. The addition of large amounts of ferro-silicon to the ladle without previous melting is not wise, and such additions will not mix easily with the molten iron. The acid-resisting properties of cast iron increase with an increase in silicon content.

Metallography and Refining of Cast Iron. A. Achenbach. (*Die Giesserei*, 1927, Vol. 14, Oct. 22, pp. 724-743). The author discusses the constitution and structure of cast iron, and gives details of various processes for its refinement.

A Note on Phosphide Eutectic. A. Allison. (*Metallurgist*, 1928, Jan. 27, pp. 3-4). The author describes three cases concerning chilled iron rolls in which phosphide eutectic gave trouble. In two cases excrescences on the surface of the barrel occurred; their phosphorus contents were 3.03 and 3.28 per cent., while the barrels contained 0.44 and 0.63 per cent. respectively. In the third case hard spots were found while turning the radius between the grey iron neck and the chilled barrel; a chisel punch and hammer caused the ejection of small egg-shaped pellets, leaving neat and clean bright cavities. One pellet contained 3.74 per cent. of phosphorus and another 4.32 per cent. The structure of the pellets, and the mode of formation of the pellets and of the excrescences, are discussed.

The Problem of Sulphur in Cast Iron and in Steels. J. Ciochina. (*Chimie et Industrie*, 1927, Vol. 18, Oct., pp. 600-604). A continuation of previous work (*see Journ. I. and S.I.*, 1927, No. I. p. 915; 1927, No. II. p. 648), in which the author set out to prove that, in irons and steels which contained sulphur, some of that element was present in the free state. He discusses some of the known properties of irons and steels in the light of that hypothesis, and asserts that the facts fit in with the theory. The loss of sulphur in mixers, without any remarkable variation in the amounts of the other elements (C, P, Mn, Si), is explained by the assumption that the sulphur is "free" and is liberated as such. On the same basis is explained the fact that cast iron remelted in the cupola and held in the electric furnace for 25 minutes loses much of its sulphur. The behaviour of sulphur in the blast-furnace and its reactions with the burden are also touched upon. The solubilities of sulphides of iron and manganese are discussed, and it is pointed out that a balance-sheet for the sulphur entering the blast-

furnace is always low, the loss, as explained by the author, being due to the escape of free sulphur while the furnace is being tapped.

Behaviour of Iron in Presence of Other Elements. G. Tammann and K. Schaarwächter. (*Zeitschrift für anorganische und allgemeine Chemie*, 1927, Vol. 167, Nov. 1, pp. 401-410). Heating curves of iron with sulphur, phosphorus, calcium, aluminium, tin, graphite, and silicon are given.

Chilled Cast Iron, its Properties and Commercial Applications. H. Bator. (*Die Giesserei*, 1928, Vol. 15, Feb. 10, pp. 121-127).

Growth of Cast Iron. E. Morgan. (*Bulletin of the British Cast Iron Research Association*, 1928, Apr., No. 20, pp. 7-17).

The Electrical Resistance of Cast Iron. H. Pinsl. (*Giesserei-Zeitung*, 1928, Vol. 25, Feb. 1, pp. 73-83; *abstract*, *Foundry Trade Journal*, 1928, Vol. 38, Apr. 26, pp. 303-306).

Malleable Iron. F. H. Hurren. (Paper read before the Institute of British Foundrymen: *Foundry Trade Journal*, 1928, Vol. 38, Apr. 26, pp. 301-302). The author outlines the influence of various elements on white-heart cast iron. A section is devoted to the common troubles encountered, and a new theory is exposed to account for cracking during annealing, based on the presence of iron sulphide resulting from low manganese content.

The Black Heart of Malleable Castings. O. Quadrat and J. Koritta. (*Die Giesserei*, 1927, Vol. 14, Dec. 3, pp. 849-854; *abstract*, *Foundry Trade Journal*, 1928, Vol. 38, Mar. 15, pp. 191-192). The authors have investigated the mechanical properties of the core of black-heart malleable castings, to determine the conditions for heat treatment.

The Strength Properties of Malleable Cast Iron. R. Stotz. (*Die Giesserei*, 1928, Vol. 15, Feb. 17, pp. 145-148).

Revised Recommendations for the Standardisation of Malleable Iron. R. Stotz. (*Die Giesserei*, 1928, Vol. 15, Mar. 16, pp. 248-249). The author presents the revised recommendations of the German Standards Committee, based on suggestions submitted by the Association of German Malleable Iron Foundrymen.

PROPERTIES AND TESTS OF IRON AND STEEL.

Emery-Tatnall 1,000,000-lb. Universal Testing Machine. (*American Machinist*, European Edition, 1927, Vol. 67, Nov. 26, pp. 638). The machine, claimed to be the largest testing machine ever built, is intended

for tensile, compressive, and transverse tests on all kinds of railway materials. The space between the columns is 7 ft., and specimens up to 19 ft. high can be accommodated. The heavy base contains the hydraulic gear for applying the stresses, to which power is supplied by a 20-H.P. motor, and the maximum movement of the lower cross-head, to which the bottoms of the specimens are attached, is 12 in. The upper cross-head carrying the weighing system is supported by two columns on which threads are turned. Motor-driven nuts enable the position of the top cross-head to be altered to suit the specimens, and permit the use of the cross-head itself as a crane for handling heavy specimens into place.

Machines for Making Cupping and Tensile Tests on Sheets. R. Guillery. (*Revue de Métallurgie, Mémoires*, 1928, Vol. 25, Mar., pp. 148-150). The author's combined cupping and tensile testing machine is illustrated and described.

The Yield Point in Steel at Various Temperatures. J. Muir. (*Journal of the Royal Technical College, Glasgow*, 1927, Dec., No. 4, pp. 14-23). Experiments are described showing the yield points observed in simple tension tests made on steel wires, electrically heated. Attention is drawn to the enormous increase in the rate at which extension occurs at the yield point even when the temperature is no higher than 50° C.; and to the fact that the phenomenon of the yield point disappears at a temperature between 215° C. and 250° C.

On the Significance of the Proportional Limit of Steel at Elevated Temperatures. F. B. Foley. (*Transactions of the American Society for Steel Treating*, 1928, Vol. 13, May, pp. 813-828). The testing of metal at elevated temperatures presents problems not encountered at atmospheric temperatures. The most valuable and most difficult value to determine is the true elastic limit. The author suggests the possibility of developing a mathematical expression for the relationship of the proportional limit determined at elevated temperatures to that obtained at room temperature, and gives evidence from available data of a straight line relationship between the temperature of testing and the sum of two factors: namely, the strain produced at the proportional limit and the thermal expansion at the temperature of testing.

The Tensile Testing of Steel Castings. (*Heat Treating and Forging*, 1928, Vol. 14, Feb., pp. 163-166). The method of determining physical properties by the tensile test, and correct and incorrect positions from which to take test-pieces, are discussed.

Normal and Shear Stress in the Testing of Materials. P. Ludwik. (*Zeitschrift des Vereines deutscher Ingenieure*, 1927, Vol. 71, Oct. 29, pp. 1532-1538; *abstract*, *Metallurgist*, 1928, Feb. 24, pp. 28-30).

An Unusual Tensile Fracture. E. C. Wadlow. (Engineering, 1928, Vol. 125, Jan. 13, p. 55). Tensile tests were carried out on a nickel-chrome steel (carbon 0.33, nickel 4.64, chromium 1.53 per cent.) after various heat treatments. One series was air-hardened from 830° C., and then reheated to 600° C. once, twice, three times, and four times, being slowly cooled on each occasion. In all cases, except those in which the specimen was reheated three times, the fracture was normal, but in the latter case an abnormal fracture occurred in all three test-pieces examined. The specimen necked considerably in the usual way, but fracture ensued along three planes, two transverse about $\frac{5}{16}$ in. on either side of the middle of the neck, and the other between these two along the geometrical axis of the specimen. The author, though unable to give an explanation of the phenomenon, is of opinion that it was not due to flaws, but must be connected in some way with the heat treatment.

Problems in Compression of Metals. E. Siebel. (Archiv für das Eisenhüttenwesen, 1928, Vol. 1, Feb., pp. 543-548; Stahl und Eisen, 1928, Vol. 48, Mar. 29, pp. 403-405; *abstract*, Plastic Compression, Metallurgist, 1928, Apr. 27, pp. 57-58). The nature of the stresses occurring in cylindrically shaped steel specimens has been studied. These stresses are of a particularly complex character—for example, when cylindrical specimens are crushed between two flat surfaces, the strength values obtained are found to differ greatly according to the ratio of the diameter to the height of the specimen. It has been recognised that the reason of this is that the friction of the pressure surface hinders the sideways movement of the particles of the material in the neighbourhood of the pressure surface. This difficulty is got over by using conical surfaces in the compressor, and an instrument for carrying out cone compression tests is illustrated. Further experiments investigated the flow of material under compression, and when forged into round bars between flat surfaces, or between a flat surface and a V-shaped groove.

The Bending of Steel Overstrained by Tension. J. Muir. (Journal of the Royal Technical College, Glasgow, 1927, Dec., No. 4, pp. 24-32). In this paper the effect which tensile overstrain has on the resistance which mild steel offers to compression is investigated by means of bending tests.

Spatial Stress Conditions and their Bearing on the Testing of Materials. P. Ludwik. (Archiv für das Eisenhüttenwesen, 1928, Vol. 1, Feb., pp. 537-542). Many of the peculiarities observable in the working and testing of materials are explicable only by regarding stress as a spatial concept. The author enlarges upon this theory in explaining phenomena associated with tensile and compression tests, and with stresses due to heating, contraction, and cold-working.

Investigations into the Straining of Rectangular and Ribbed Tubes by Internal Pressure. E. Siebel. (Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1927, Vol. 9, No. 20, pp. 295-317).

Destruction Test of a 66-in. Forged Steel Penstock Pipe. J. L. Cox. (Paper read before the American Society of Mechanical Engineers, Dec. 5-8, 1927: Mechanical Engineering, 1927, Vol. 49, Dec., pp. 1307-1308). The method of testing and the results obtained are described. The pipe failed at about the pressure calculated by the Birnie formula arbitrarily extended to the ultimate strength.

The Choice of Testing Methods for the Acceptance of Structural Steels. Ch. Frémont. (Génie Civil, 1928, Vol. 92, Mar. 24, pp. 280-283).

The Testing of Materials. V. E. Green. (Proceedings of the Staffordshire Iron and Steel Institute, 1925-26, Vol. 41, pp. 23-30). A brief account is given of methods for carrying out routine and laboratory tests of steel.

The Strength of Flat Plates. T. A. Bryson. **The Strength of Flat Plates.** T. Cheeger. **The Stresses in Flat Plates.** H. H. Gorrie. (Rensselaer Polytechnic Institute, Engineering and Science Series, 1928, No. 18).

The Testing of the Strength Properties of Metallic Constructional Materials. M. Rudeloff. (Die Giesserei, 1928, Vol. 15, Mar. 2, pp. 196-200; Mar. 9, pp. 217-225; Mar. 16, pp. 237-245; Mar. 23, pp. 263-272; Mar. 30, pp. 289-297). Numerous types of German testing machines are illustrated and briefly described.

Factors of Safety and Quality of Material. W. H. Riddlesworth. (Paper read before the Institution of Engineers and Shipbuilders in Scotland, Dec. 20, 1927: Engineer, 1927, Vol. 144, Dec. 30, pp. 748-749). The author discusses the true meaning of the expression "factor of safety"; he indicates some of the considerations which should govern its magnitude, and relates it to the appropriate strength property of the material to afford some guidance towards a proper choice of the materials available.

The Fatigue-Resisting Properties of 0.17 per cent. Carbon Steel at Different Temperatures and at Different Mean Tensile Stresses. H. J. Tapsell. (Paper read before the Iron and Steel Institute, May 1928: this Journal, p. 275).

Fatigue Tests of Carburised Steel. H. F. Moore and N. J. Alleman. (Transactions of the American Society for Steel Treating, 1928, Vol. 13,

Mar., pp. 405-419). The authors present the results of fatigue tests and static tension tests of carburised steel. Three steels were studied ; a plain carbon steel, a nickel steel, and a chromium-nickel steel. Several different treatments were tried for each steel. In general, the results suggest that carburising, followed by a suitable heat treatment, is a promising means of increasing the fatigue strength of steel as well as an effective means of increasing surface hardness. Steel quenched in oil from the carburising pot showed more increase in fatigue strength than did steel cooled in the carburising pot.

Fatigue as a Result of Prolonged Critical Static Loading. G. Welter. (*Zeitschrift für Metallkunde*, 1928, Vol. 20, Feb., pp. 51-56). The influence of time on the properties of materials at critical loads was determined. The effect of temperature was also investigated. A three-dimensional diagram is given showing the dependence of the strength of the material on these two factors. Iron, brass, and aluminium and magnesium alloys were employed in the research.

Why Some Drill Rod Steels Fail. O. E. Harder. (*Iron Age*, 1928, Vol. 121, Feb. 23, pp. 532-534). The author has examined what appears to be a typical progressive fatigue failure in a diamond drill rod. In addition to the one fracture which caused failure, there were four others starting from the inside of the tube and progressing outward. A combination of notch effect and corrosion is suggested as the cause of the position of the cracks. It is also indicated that the quality of the steel as revealed by the microstructure has an important bearing in progressive fatigue failures.

Fatigue Cracks in Axles. (*Metallurgist*, 1927, Dec. 30, pp. 181-183). A review of the work of various investigators who have examined the surface manifestations of fatigue.

The Fatigue of Metals. D. Hanson. (*Proceedings of the Staffordshire Iron and Steel Institute*, 1926-27, Vol. 43, pp. 13-30).

What Changes do the Mechanical Properties suffer through Fatigue ? J. Czochralski and E. Henkel. (*Zeitschrift für Metallkunde*, 1928, Vol. 20, Feb., pp. 58-62). Test-bars were subjected to fatigue in a machine of the rotating beam type, and the relationship between their mechanical properties after straining to the amount of fatigue applied was determined. Copper, aluminium, and steel test-pieces, both hard-drawn and soft annealed, were used. During the tests cracks having a common direction were found to develop on the surfaces of the pieces, and these were proved to be caused by the final rub with emery given before testing ; on rubbing parallel to the axis of the specimens the orderly arrangement of the cracks disappeared. The authors explain the fatigue phenomena observed by means of " planes of equal minimum strength " within the test-pieces.

On Vibration Measurements. J. Oelschläger. (Röhrenindustrie, 1928, Vol. 21, Mar. 1, pp. 113-114; Mar. 29, pp. 151-152). A description of apparatus for the measurement of transverse, longitudinal, and torsional vibrations in tubes.

The Rotating Vibrational Testing Machine and the Results Obtainable with It. O. Föppl. (Zeitschrift für Metallkunde, 1928, Vol. 20, Apr., pp. 142-144).

Surface Sensitivity and Internal Absorption of Work of Materials under Vibrational Stress. E. Lehr. (Zeitschrift für Metallkunde, 1928, Vol. 20, Feb., pp. 78-85).

Long-Time Failure as a Dynamic and Vibrational Phenomenon. W. Hort. (Zeitschrift für Metallkunde, 1928, Vol. 20, Feb., pp. 40-43). The author first discusses the Wöhler test and the stresses in machine parts. He then deals with the characteristics of the phenomena of long-time failures, vibration, and the action of notches and of impact. A few words are added on the testing of the long-time strength of materials.

A General Consideration of Long-Time Failure. J. Czochralski. (Zeitschrift für Metallkunde, 1928, Vol. 20, Feb., pp. 37-39). The author discusses, in a general way, the phenomena of the fracture of materials under load in the course of a long period.

Statical Hysteresis in Cycles of Equal Load Range. G. H. Keulegan. (United States Bureau of Standards, 1928, Technologic Paper No. 365). The present paper deals with an investigation made for the purpose of ascertaining the influence of the extreme loads on the energy hysteresis loss in the cycles of equal load range during the flexure of an Armco iron bar. It is an extension of work reported in Bureau of Standards Technologic Paper No. 332. The flexure of the bar is considered for the case where one end of the bar is clamped and the other end loaded. Since in Armco iron the hereditary hysteresis is negligible in comparison with the statical hysteresis, the results of the experiment apply mainly to statical hysteresis. Cycles of small extreme loads only are considered, and the conclusion derived from the result of the experiments is to the effect that the energy loss due to statical hysteresis in cycles of equal load range is independent of the extreme loads.

The Most Important Properties and the Theory of Strain Figures. I. Takaba and K. Okuda. (Archiv für das Eisenhüttenwesen, 1928, Vol. 1, Jan., pp. 511-515; *abstract*, **Strain Figures and their Origin**, Metallurgist, 1928, Apr. 27, pp. 58-59). Mild steel rectangular bars, supported at two places, were loaded at a position half-way between the supports; strain figures were then produced by Fry's method.

The internal distribution of stress was determined by Coker's polarised light method, using celluloid test-pieces to find the directions of the stresses and bakelite for their magnitudes. By these means it was shown that the strain figures originated at regions of maximum shear and spread into regions where the stress was relatively high. Other experiments gave rise to the conclusion that the kink in the load-extension curve and the formation of strain figures are manifestations of a single phenomenon. The authors draw attention to the fact that strain figures are found only in materials having a body-centred cubic type of space lattice.

Elasticity and Plasticity. E. G. Coker. (Proceedings of the Institution of Mechanical Engineers, 1926, Vol. 2, pp. 897-941). The following subjects are considered: Determinations of stress distribution in elastic bodies; comparison of stress distributions in different elastic materials; shear stress diagrams; theories of failure of elastic condition of materials; plasticity; and distribution of shear stress in twisted shafts. The author also considers some of the more recent developments in the science and technique of photo-elasticity. A bibliography of 41 references to the subject is included.

Properties of Materials at High Temperatures. III.—Note on the "Creep" of Armco Iron. H. J. Tapsell. (Department of Scientific and Industrial Research, Engineering Research, Special Report No. 6, 1928). The author describes an investigation, the results of which show that strain-hardened Armco iron may be further hardened by temperatures at least between 150° and 390° C., and that both strain-hardening and temperature-hardening occur during a creep test. Plasticity appears to decrease and give place to apparent perfect elasticity under conditions of prolonged stress at temperatures below the limiting creep values.

Creep in Five Steels at Different Temperatures. H. J. French, H. C. Cross, and A. A. Peterson. (United States Bureau of Standards, 1928, Technologic Paper No. 362). This report describes so-called creep tests in which the elongation of metal specimens with time is observed under a fixed load. Tests were made on a low-carbon structural steel, a high-chromium steel, a chromium-molybdenum structural steel, high-speed steel, and a high-chromium high-nickel austenitic steel, and correlated with short-time tension tests at corresponding temperatures within the range 70° to 1350° F. (20° and 730° C.). So-called creep charts are given in which the relations are shown between stress, temperature, elongation, and time for each of the steels. These charts enable the approximate determination of the stress permitting life of different durations with different total elongations. The application of these charts is discussed in some detail. Correlation of creep tests with short-time tension tests shows that, when using accurate

equipment, the proportional limit was in the range of stresses which could be sustained for long periods with small amounts of deformation. The best resistance to oxidation in air was shown by the high-chromium high-nickel steel and the high-chromium steel. These appear to be superior to the high-speed steel, which, however, with the high-chromium high-nickel steel showed the best load-carrying ability in the range 1100° to 1350° F. (595° to 730° C.). The chromium-molybdenum steel was not structurally stable at 1200° F. (650° C.). Oxidation was accompanied by decarburisation and grain growth.

Brinell Hardness, Static Flexure, and Shearing. R. Guillery. (*Revue de Métallurgie, Mémoires*, 1928, Vol. 25, Mar., pp. 151-154). The author's machine for making these three tests is described and illustrated.

Equipment for Making Physical Tests. J. D. Gat. (*Heat Treating and Forging*, 1927, Vol. 13, Dec., pp. 473-475; 1928, Vol. 14, Jan., pp. 38-40). The features of the Brinell, Scleroscope, Vickers, and Rockwell hardness testing machines, of loaded beam and hydraulic tensile testing machines, and of Izod, Charpy, and Humphrey impact testing machines, are described and compared. Notes on the preparation of microscope specimens and on the microscope equipment are also given.

Tests in Locating Faults of Treatment. J. D. Gat. (*Heat Treating and Forging*, 1928, Vol. 14, Feb., pp. 146-149; Mar., pp. 274-276). The author describes means for distinguishing between faults due to incorrect treatment and those due to inferior quality of the steel. Causes of failure and their correction are exemplified.

An Improved Hardness Tester. (*Iron Age*, 1928, Vol. 121, Mar. 1, pp. 602-603). The design and operation of the Vickers diamond pyramid hardness tester is described and illustrated.

Hardness Tester for Gear Teeth. (*American Machinist, European Edition*, 1927, Vol. 67, Dec. 17, pp. 229E-230E). **Testing the Hardness of Gear-Wheel Teeth.** (*Engineer*, 1927, Vol. 144, Dec. 2, p. 635). An attachment for use with Vickers hardness testing machines is described, by which diamond indentations may be made on a gear-wheel tooth as far in as the pitch line without the necessity for removing a neighbouring tooth and so destroying the wheel.

The Recovery and Sinking-In or Piling-Up of the Material in the Brinell Test and the Effects of these Factors on the Correlation of the Brinell with certain Other Hardness Tests. A. L. Norbury and T. Samuel. (Paper read before the Iron and Steel Institute, May 1928: this Journal, p. 673).

Report on Diamond Cone Indentation Hardness Tests. G. A. Hankins. (Proceedings of the Institution of Mechanical Engineers, 1926, Vol. 2, pp. 823-842). The author describes an investigation, the results of which show that diamond cones can be used for accurate and reliable indentation tests on hard materials, and when the results are corrected for adhesion or friction, direct comparison can be made with steel cone or ball test results on softer materials. The 120° diamond cone is considered the most satisfactory shape for general use. This form of test can be recommended for general use on all steels over 300 Brinell number, and the results should be obtained from the measured diameter of the indentation by means of the formula :

$$\text{Corrected cone hardness} = \frac{\text{Load in kg.}}{\pi r^2 \times 1.058}$$

Results obtained in this way are numerically the same as Brinell numbers up to the value of 440. Above this value flattening of the ball may occur, and it is considered that the diamond cone is thus much more reliable than the steel ball test. On very hard steels the diamond cone gives indentations which are easily measured, and the results can be simply expressed on a rational indentation scale. A result is independent of the applied load, but a load of 100 kg. would probably be found satisfactory for general use. For very thin sheet much lower loads could be used, provided the point of the diamond cone was accurately ground and sufficient accuracy was used in measuring diameters of indentations.

Relationships between Rockwell, Brinell, and Scleroscope Numbers. R. R. Moore. (Transactions of the American Society for Steel Treating, 1927, Vol. 12, Dec., pp. 968-975). The paper gives the results of a large number of Rockwell, Brinell, and Scleroscope tests made on a number of structural alloy steels under various conditions of heat treatment, giving a range of hardness from 145 to 625 Brinell. A table is included which shows the relationship between Rockwell C (diamond), Scleroscope, Brinell, and Rockwell (B, $\frac{1}{16}$ -in. ball). Graphs are given which compare Rockwell-Brinell, Rockwell-Scleroscope, and Rockwell C-Rockwell B $\frac{1}{16}$ relationships obtained by the author and other investigators.

The Impact Hardness Testing Apparatus. I. Class. (Zeitschrift des Vereines deutscher Ingenieure, 1927, Vol. 71, Nov. 26, pp. 1680-1682; *abstract*, Metallurgist, 1928, Feb. 24, pp. 22-23). An illustrated description is given of a portable apparatus for the measurement of ball hardness by impact. The apparatus, which weighs under 4½ lb., depends for its action upon the release of a compression spring which produces a sharp blow on the collar of a spindle fitted with a steel ball at its end. The instrument is used in a horizontal position, and it is necessary that the specimen and the block on which it is supported

should have sufficient inertia to ensure that all the impact energy is used in forming the impression. The instrument can be calibrated to give curves connecting the Brinell number with the diameter of the impression obtained.

The Impact Resistance of Steels at Low Temperatures. I. F. Morrison and A. E. Cameron. (Transactions of the Canadian Institute of Mining and Metallurgy, 1927, Vol. 30, pp. 839-857). The authors describe an investigation to determine changes in Charpy impact values with changes in temperature, and to determine what heat treatment is best adapted for steel to resist shock at low atmospheric temperatures. Two carbon steels (0.10 and 0.34 per cent. carbon) were used in the investigation. From the results of the investigation the following practical conclusions have been drawn. Low temperatures, in all cases, lower the impact resistance of low- and medium-carbon steels. In the normalised condition the impact resistance is markedly decreased for temperatures below 0° F. At -20° F. the impact resistance of low-carbon steel is less than one-tenth, and of medium-carbon less than one-third, the resistance of these steels at room temperatures. Obviously steel in this condition is in the most unsuitable condition to withstand shock at temperatures below 0° F. Any heat treatment, other than normalising or annealing, is preferable where a low- or medium-carbon steel is to be subjected to shock when under the influence of temperatures at least as low as -25° F. Plain carbon steels in a quenched and fully drawn condition offer greater resistance to impact at low temperatures than for any other heat treatment. In the case of plain carbon steels that are likely to be subjected to shock at temperatures below 0° F., for best service it is necessary to give the steel some heat treatment other than annealing or normalising. In general, the authors would recommend proper quenching followed by drawing at temperatures around 1100° F. In the case of street-car axles for use in cities in northern latitudes, it seems advisable to recommend that they be purchased with a specified heat treatment as outlined above. The general practice of annealing axles after a period of service is detrimental from the point of view of resistance to impact. From the investigations, the authors feel that this practice may account for some of the failures during cold weather.

Experimental Researches on the Speeds of Deformation of Metals at High Temperatures. P. Henry. (Revue de Métallurgie, Mémoires, 1927, Vol. 24, Aug., pp. 421-422; *abstracts*, **The Behaviour of Metals at High Temperatures** (Metallurgist, 1927, Dec. 30, pp. 180-181; Journ. I. and S.I., 1927, No. II. p. 604).

The Properties of Steel at Low and High Temperatures. A. Pomp. (Zeitschrift des Vereines deutscher Ingenieure, 1927, Vol. 71, Oct. 22,

pp. 1497-1502; *abstract*, Metallurgist, 1928, Jan. 27, pp. 13-14). Short-time tests to determine the life of steels at high temperatures are described; an empirical limit was assigned to the stress for long life, namely, that stress below which the extension did not exceed 0.001 per cent. in from 3 to 6 hrs. after application of the load. The influence of the method of loading upon the temperature effect is demonstrated; for instance, tensile tests at 200° to 300° C. indicate in many cases that the metal is brittle, but notched-bar tests within that range almost always give results higher than at room temperature. A chrome-nickel steel containing carbon 0.23, chromium 0.78, and nickel 0.75 per cent. is shown to have valuable strength properties at very low temperatures; after normalising, its impact strength at - 80° C. is of the same order as that of a good normalised mild steel at about 0° C. It is shown that the extreme brittleness of 4 per cent. silicon steel, used in electrical work, which makes it troublesome to deal with at ordinary temperatures, may be overcome by working at 200° to 300° C.

Investigation of the Notched-Bar Impact Test, with a View to the Standardisation of this Method of Testing. Schwinning. (International Congress for the Testing of Materials, Amsterdam, 1927, Vol. 1, pp. 207-228).

History and Present Status of the Notched-Bar Test. A. Horzenberger. (Mitteilungen des Staatl. Technischen Versuchsamtes (Vienna), 1927, Vol. 16, Nos. 1-3, pp. 135-144).

The Causes of the Wear of Firebars. K. Hofer. (Glückauf, 1928, Vol. 64, Feb. 18, pp. 211-215). The principal causes of the wear of firebars are the oxidation of the iron by the oxygen of the air at high temperature, and that the iron oxides formed are dissolved by the attack of the viscous clinker. The best means of prevention of wear are: (1) To provide means of cooling the bars so as to keep them at a temperature below that at which oxidation of the iron takes place; (2) by coating the upper surface of the bar with a layer of aluminium or chromium; and (3) the hardening of the surface of the bar by suitable treatment.

Recent Experiments relating to the Wear of Plug Gauges. H. J. French and H. K. Herschman. (Transactions of the American Society for Steel Treating, 1927, Vol. 12, Dec., pp. 921-953). Results are given of tests made in a laboratory wear tester in gauging file-hard high-carbon steel, an aluminium "piston alloy," and a cast iron. Of the various gauge metals investigated, chromium-plated gauges showed the highest resistance to wear under conditions of metal-to-metal contact. Ammonia-treated chromium-aluminium steel, known as Nitralloy, was second in order of resistance to wear. These two metals

were much superior to the remainder of the group, which showed variations but no radical differences in wearing properties. In the abrasive wear tests, Stellite, a high-carbon high-chromium alloy, and the chromium-plated gauges showed better resistance to wear than the high-carbon steels or the Nitralloy.

An Investigation into Some Effects of Cold-Drawing on the Strength and Endurance of Mild Steel. R. M. Brown. (Paper read before the Institution of Engineers and Shipbuilders in Scotland, Feb. 21: Iron and Coal Trades Review, 1928, Vol. 116, Mar. 9, p. 341). It is concluded that within limits of the present investigation the cold-drawing of mild steel—(1) increases the tensile strength; (2) decreases ductility in tension; (3) increases the Wöhler endurance range, but decreases the ratio:

$$\frac{\text{Wöhler range}}{\text{ultimate tensile strength}};$$

- (4) increases the endurance range for direct stresses (Haigh cycle);
(5) increases the ratio:

$$\frac{\text{Haigh range}}{\text{ultimate tensile strength}}$$

for all values of mean tensile stresses, but decreases the ratio when the mean stresses are compressive; (6) decreases the Izod value to a minimum value, but that further cold-work appears again to cause an increase; (7) does not produce a directional effect on tensile or Wöhler properties—for small amounts of cold-work.

Hardening by Reheating after Cold-Working. M. A. Grossmann and C. C. Snyder. (Transactions of the American Society for Steel Treating, 1928, Vol. 13, Feb., pp. 201–220, 281). Cold-worked steel becomes progressively less ductile when it has been reheated at low temperatures up to 315° C., and after passing that temperature becomes progressively more ductile. There is evidence to support the hypothesis that these phenomena originate in the amorphous metal produced by cold-work. The grains of the metal appear to deform by “block slip,” the regions between the blocks becoming amorphous. Low-temperature reheating causes hardening due to the amorphous layers, presumably by the growth of the thin layers which obstruct deformation. The lowest temperatures merely cause the thin layers to grow to effective size, but reheating to higher temperatures causes them to grow to such size that they become ductile and are no longer effective in obstructing slip. In the reheating of quenched steels, the brittle range which develops in the neighbourhood of 315° C. is due to the presence of non-ductile transformed austenite in a matrix of tempered martensite. The non-ductile regions obstruct the deformation of the softer matrix.

The Microscopic Analysis of Wire. J. D. Brunton. (Wire, 1927, Vol. 2, Dec., pp. 420-423, 434-440). The crystalline deformations due to cold-working, and the microstructural influence of annealing, rate of reduction, uniformity of flow, &c., are studied.

Plastic Flow and the Strength of Cold-Worked Steel. E. B. Norris. (Engineering News-Record, 1927, Vol. 99, Oct. 6, pp. 548-549).

Changes in Structure and Electric Resistance of Cold-Worked Metals. G. Tammann and M. Straumanis. (Zeitschrift für anorganische und allgemeine Chemie, 1928, Vol. 169, Feb. 11, pp. 365-380).

Cold-Work by Compression and the Brittleness of Steel. Existence of a Limit of Brittleness. P. Dejean. (Revue de Métallurgie, Mémoires, 1927, Vol. 24, July, pp. 415-417; *abstracts*, **Impact Properties of Steel after Cold Compression** (Metallurgist, 1927, Nov. 25, pp. 165-166; Journ. I. and S.I., 1927, No. II. p. 615).

The Energy absorbed and the Conditions of Temperature of Crystallisation and Cold-Working Effect produced by the Deformation of Metals. H. Giersberg. (Thesis presented to the Technical High School at Breslau, 1926, pp. 1-18).

The Effect of Heat Treatment on Cold-Drawn Steel Tubes. F. C. Lea. (Engineering, 1927, Vol. 124, Dec. 23, pp. 797-800; Dec. 30, pp. 831-834). Part I. of the article reports the results obtained in statical and repetition stress tests on 0.35 per cent. carbon steel tubes designed to determine the effect of annealing at various temperatures on the properties of the cold-worked tubes and their relationship to the fatigue range. Compression tests on specimens $3\frac{1}{2}$ in. long, and on specimens 1 in. long cut from them after the first test, torsional tests, endurance tests, repeated stress tests and density determinations were made. Part II. deals with determinations of the effect of pinch and sink on the properties of 0.15 and 0.30 per cent. carbon steel tubes, tests being made on tubes after normalising at 880° C. before the final pass, after cold-drawing to $1\frac{1}{8}$ in. outside diameter, on cold-worked tubes after heat treatment at 400° C. and after heat treatment at 550° C. Compression, bending, and torsion tests were carried out.

The Effect of Drawing and Blueing on the Physical Properties of Wire. J. D. Brunton. (Wire, 1928, Vol. 3, Feb., pp. 47-49, 66-69).

Stress Relationships in Forging and Rolling. F. Körber and E. Siebel. (Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1928, Vol. 10, No. 2, pp. 15-22). The stress relationships in forging and rolling under conditions of elastic and plastic change of shape were determined. Henky and Prandtl's laws for the equilibrium

in plastic bodies served as a basis for dealing with the condition of change of shape in two dimensions. The assumptions made as to the form of slip plane systems were verified by the experiments. It became evident that in the processes of change of shape in question the occurrence of transverse stresses is to be reckoned with, which provides the explanation of a number of phenomena encountered in the technical operation of these processes. These considerations were supplemented by an investigation of spread phenomena and of the stress relationships introduced by the flow of the material in three-dimensional space.

Changes in Orientation of Crystallites of Steel due to Rolling. G. Tammann and A. Heinzel. (*Zeitschrift für anorganische und allgemeine Chemie*, 1927, Vol. 167, Oct. 14, pp. 173-182).

Orientation of Crystallites in Stretched and Compressed Metals, and the Crystallographic Interpretation of the Slip Phenomena occurring in the Stretching, Compressing, and Rolling of Metals. G. Tammann and A. Heinzel. (*Archiv für das Eisenhüttenwesen*, 1928, Vol. 1, Apr., pp. 663-667). By determining the maximum lustre of etched metal surfaces it is possible to determine the orientation of the crystallites in stretched bars and in compressed cubes, and to follow their progressive change as the degree of stretching or compression changes. This method has the advantage over the Röntgen ray measurement method that the changes in orientation of the crystallites can be observed over larger regions.

Effect of Annealing on Cold-Worked Single Crystals of Silicon-Ferrite. H. O'Neill. (American Institute of Mining and Metallurgical Engineers, 1928, Technical Publication, No. 48). Subcutaneous deformation markings are revealed on etching polished sections of slowly cold-worked single crystals of silico-ferrite. Scratch tests indicate the concentration of strain hardness at these etch-bands, and also the increase of strain hardening from the base to the line of fracture of a sectional crystal "fracture wedge." Annealing these cold-rolled single crystals at 250° C., either shortly after rolling or after a rest of twenty months, gave no measurable rise of scratch hardness. With such a heat treatment a hardening effect might have been expected; if anything, a slight softening was indicated. Heating at higher temperatures caused pronounced softening of a crystal fracture wedge before any sign of metallographic recrystallisation could be detected. Incipient recrystallisation was observed at two points in the main "etch band" system after heating a certain crystal fracture wedge at 740° C. for 30 minutes. Recrystallisation and softening was then progressive in the sense that the use of (a) longer periods of annealing at a given temperature, or (b) higher temperatures, caused further general softening and the appearance of more new grains, together with some growth of previously existing grains. After these

annealing treatments no recrystallisation was apparent in the less distorted basal portions of the fracture wedge. Generally speaking, a major axis of the new grains followed the direction of the "etch bands." The soft recrystallised grains were generally surrounded by relatively severely strain-hardened metal, and their scratch hardness was higher than that of the annealed unstrained head of the crystalline test-piece. This suggests that the new grains were still subjected to some hardening strains. The effect of a long time interval between deformation and heat treatment was to retard both softening and recrystallisation. Scratch tests have demonstrated: (a) that a hard surface layer can be produced on metallic crystals by polishing, and that this layer can be removed by etching; (b) that annealing a metallic crystal in the "as cast" condition causes it to soften; (c) that the hardness varies in different directions along a given crystallographic face, and appears to be least in the direction parallel to the traces of (001) planes.

Internal Stresses. (Metallurgist, 1928, Jan. 27, pp. 7-8). The article is based on the work of Maurer, Heyn and Bauer, Sachs, Arkel, and others; it deals with the approximate estimation of the nature and magnitude of internal stresses by mathematical means, and their detection by spectroscopic X-ray examination. Heat treatment for modifying the stresses is also briefly referred to.

An Optical Method of Determining Internal Stresses in Homogeneous Materials. C. F. Ffolliott. (Rensselaer Polytechnic Institute, Engineering and Science Series, 1927, No. 17). A brief discussion of the photo-elastic method of determining stress distribution.

Properties and Tests of Thin Plates for Drawing Processes. W. Aumann. (Maschinenbau, 1928, Vol. 7, Feb. 2, pp. 105-110). Apparatus and methods are described for testing thin plate used in the drawing of hollow cylindrical parts.

Observations on Testing of Sheet Steel. (Forging, Stamping, Heat Treating, 1927, Vol. 13, Nov., pp. 435-438). A comparison is made of the testing methods and the internal defects noted in the deep and extra deep drawing of sheet steel; segregation, inclusions, &c., are considered. The opinion is expressed that the Olsen ductility testing machine is the most rapid and fairly accurate tester, and in conjunction with the microscope offers a complete means of studying and recording deep and extra deep drawing sheet steel.

Wire Ropes Research. W. A. Scoble. (Third Report of the Wire Ropes Research Committee of the Institution of Mechanical Engineers; Engineering, 1928, Vol. 125, Apr. 27, pp. 522-525). The present report records the results of repeated bending tests of a set of wire

ropes, constructed of wire having a tensile strength of 100 to 110 tons per sq. in. Reversed bending tests of ropes and tests of single wires were also carried out.

Some Causes of Failure in Wire Mining Ropes. C. H. Desch. (Paper read before the Midland Institute of Mining Engineers: Iron and Coal Trades Review, 1928, Vol. 116, Feb. 17, pp. 211-213). The author presents a number of observations made in the course of the examination of broken or injured ropes submitted to Sheffield University. The paper describes one rope of locked-coil construction which was externally in perfect condition, but had deteriorated badly in the inner layers. The possibility of internal decay without external signs has led several investigators to search for other methods of detecting broken and worn wires, special attention being given to magnetic methods. The most thorough investigations are those of Sanford, who found that single wires showed magnetic irregularities along their length, even without signs of damage, and that slight variations of internal stress caused variations as large as those due to severe injuries. Improvements in the method made it possible to locate defects in a single wire with greater certainty, but no definite indications could be obtained with built-up ropes. The detection of broken wires in a rope by means of X-ray examination is impracticable, and measurements of the electrical resistance have also been tried and rejected. In ropes of locked-coil construction there is a lack of flexibility, and the rope bends more in the manner of a solid bar than of a Lang's lay-rope. The friction between the layers is high, and when the lubricant is squeezed out the stresses become severe. A few general remarks are included concerning the properties of the hard-drawn wire used for ropes.

Bridge Wire Tested after 75 Years. H. C. Boynton. (Iron Age, 1928, Vol. 121, Jan. 9, p. 400). Tests were carried out on wrought-iron wire taken from the High Falls Bridge, which was erected in 1848 and demolished in 1921. The wire was designed to have a tensile strength of 90,000 lb. per sq. in. The results of tests carried out in 1921 showed the following:

Diameter	0.153 in.
Breaking strength	1,735 lb.
Ultimate strength	94,166 lb. per sq. in.
Reduction of area	25.4%

The improvement in physical properties is thought to be due to ageing.

Transverse Testing Apparatus for Wires. H. A. Holz. (Wire, 1927, Vol. 2, Oct., pp. 345, 369). In this apparatus the wire specimen is supported horizontally at its ends, and the transverse load is applied at the middle. The maximum load exerted when the test-piece breaks

is indicated by a pointer, and a chart also records the deflection/load relationship.

The Recent History of Wire Rope Testing in Germany. C. Bach. (Wire, 1928, Vol. 3, Jan., pp. 15-16, 24-29). The author reviews the results of investigations made in Germany into the wear and tear of wire ropes. "Squeezing" and "rubbing" were found to be the initial causes of failure; these factors brought about the fracture of individual wires in the ropes, and the added strain thrown on the remaining sound wires caused their ultimate breakdown. The author stresses the need for constant and thorough inspection of wire ropes. One test which he suggests consists in allowing the rope to run its length through a handful of cotton waste; any broken wires will pick up a bit of waste on the broken ends and so reveal themselves.

Brittleness in Chain Links as affected by Proofing and Annealing. I. R. Mulder. (Engineering, 1928, Vol. 125, Jan. 6, pp. 2-4). The author recapitulates briefly and discusses the tests on wrought-iron chains carried out by C. G. Lutts of the Boston Navy Yard (Proceedings of the American Society for Testing Materials, 1924, Vol. 24), and supplementary tests made at the suggestion of the Dutch Lighthouse Board in 1926-27 on steel chains.

The Failure of Wrought-Iron Chain. H. J. Gough and A. J. Murphy. (Paper read before the Institution of Mechanical Engineers, Apr. 20, 1928; Engineer, 1928, Vol. 145, Apr. 27, pp. 468-470). A series of experiments was made to study the effect of repeated static straining, with and without intermediate heat treatment, upon the strength properties of a chain and on the mechanical properties and micro-structure of the iron. Attention was then directed to the investigation of the properties of a series of wrought-iron chains drawn from service of known history. An exhaustive series of tests was made on each chain. These included static and impact tests on sample lengths of chain, together with a full series of mechanical tests made on specimens cut from chain links. All these tests were made on chain in three conditions: (1) As received; (2) after prolonged annealing at 650° C.; and (3) after normalising at 1000° C. Further experiments showed that by the application of light surface impacts new chain links and new chain iron can be made to exhibit the brittle characteristics of wrought-iron chains drawn from service in such a precise manner as to leave little doubt that the brittleness in each case arises from the same common cause. A further series of experiments showed that a brittle case covering a very ductile core will make the whole section behave in a very brittle manner under shock conditions. Failure of wrought-iron chain and cable may be caused by one or more of three main types of defect. In the first case, a brittle state may be set up as a result of overheating or burning of the chain iron during one

of the stages of manufacture, or of the chain link during the forging process. Secondly, service shocks and strains tend to bring about a progressive deterioration of the weld, and this deterioration may be of such a nature that the defect cannot be detected either by the usual method of test (proving) or by visual examination of the chain. Heat treatment cannot cure either of these two types of defect. The third and most important cause of brittleness is associated with the type of service demanded of chain and cable. As a consequence of inter-link action, hammering on the ground, snatch loading, rattling through hawse pipes, battering on chain wheels, cleaning by rumbling machines, and similar actions to which chain cable may be subjected, the material of the surface of the link, in some cases to a very small depth only, becomes locally hardened to such a degree that its ductility is practically exhausted. Hence heat treatment, either annealing at a dull red heat, or normalising at $1000^{\circ}\text{C}.$, will effectively restore the chain to a condition of great ductility by effecting recrystallisation of the hardened surface layers of the chain links. Such heat treatment must therefore be regarded only as a cure for surface embrittlement; it is not a means of prevention of the subsequent redevelopment of brittleness in service. One of the main results of the present research is, therefore, to endorse the present practice of periodical low-temperature annealing of wrought-iron chain and cable, and to place the employment of that practice on a rational basis.

Machinability of Metals. O. W. Boston. (Transactions of the American Society for Steel Treating, 1928, Vol. 13, Jan., pp. 49-94, 154). The paper gives an outline of the various methods which are in use for determining the machinability of metals, and reviews the work of various investigators on the subject. Machinability may refer to the relative machining qualities of several metals under the same conditions or to those of a given metal under varying conditions. Several methods discussed which have been used to indicate machinability are as follows: (1) The measurement of the force on a tool to cut a metal under standardised conditions. (2) The measurement of the power or energy required to remove a given chip under standardised conditions. (3) The ability of a standardised tool to cut various metals, in terms of tool life or cutting speed. (4) The measurement of the finish left on the cut surface. (5) The penetration of a standardised drill when cutting at constant speed and under given load. (6) The torque developed by a drill while drilling various metals under standardised conditions. (7) A cutting speed for a certain tool life under standardised conditions expressed in terms of physical properties of the material being cut. (8) The hardness numbers of the materials as indicated by a hardness testing machine. (9) The measurement of heat generated and the hardness induced by the cutting process. The paper terminates with a bibliography of thirty-nine references to literature on the subject.

Testing Machinability. F. Rapatz and K. Krekeler. (Stahl und Eisen, 1928, Vol. 48, pp. 257-261). The three chief methods of testing machinability are: (1) Keep's hardness drilling test. The depth of hole drilled in 100 revs. under uniform pressure on the drill serves as the standard of measurement. Kessner first devised this method and it is also known as Kessner's method. (2) By measurement of the forces opposed to cutting, *i.e.* the pressure on the feed and the turning moment. (3) Determination of the durability of the cutting edge. The drill test gives no indication of the optimum cutting speed; neither does method No. 2, though it enables judgment as to the best form of cutting edge. The weight of turnings in a given time, at given rate of feed, and depth of cut, allow the optimum cutting speed to be determined, and this serves as a good standard for judging machinability.

Machinability of Steels for Automobile Construction. G. Schlesinger. (Stahl und Eisen, 1928, Vol. 48, Mar. 8, pp. 307-312; Mar. 15, pp. 338-345). Describes an investigation on suitable cutting speeds and feeds for machining plain carbon steels and alloy steels, the last-named group including case-hardened steels and heat-treated steels.

Tests in Machining Manganese Steel. A. S. Martin. (Heat Treating and Forging, 1928, Vol. 14, Mar., pp. 282, 296). The results of tests made to determine the superior cutting qualities of a new high-speed steel by machining manganese steel (carbon 1.20, manganese about 12 per cent.) are recorded. The tests proved satisfactory. The composition of the tool steel, called Circle C steel, is not given.

Report on Cutting Temperatures: Their Effect on Tools and Materials Subjected to Work. E. G. Herbert. (Proceedings of the Institution of Mechanical Engineers, 1927, No. 2, pp. 863-908). The first part of the report gives the results of an investigation of the heat-resisting properties of high-speed steel after being subjected to various primary and secondary hardening temperatures. Part II. deals with the effect of cutting temperatures on work materials, and has special reference to the fact that steel and many other metals showed a marked decline in their capacity to be work-hardened, when they were within a restricted range of temperature, the "free-cutting range." Part III. is a short résumé of the research work that has been carried out in the hope of finding the source of the work-hardening changes in metals.

On the Quantitative Measurement of the Cutting Power of Cutlery. K. Honda and K. Takahasi. (Science Reports of the Tôhoku Imperial University, Sendai, 1927, Vol. 16, pp. 755-763. *See also* Journ. I. and S.I., 1927, No. 2, p. 357).

Evaluating Quality in Heat-Treated High-Speed Steel by Means of the Milling Cutter. J. B. Mudge and F. E. Cooney. (Transactions of the American Society for Steel Treating, 1928, Vol. 13, Feb., pp. 221-

239). The authors describe the results of a number of tests of high-speed steel in the form of milling cutters. In the tests the variables were reduced to a minimum, and the dulling point of the cutting edges of the tools was determined by a recording wattmeter connected in the circuit of the motor of the milling machine. After several trial runs "deadlines" were established which governed all future tests. It was found that cutters of the same steel hardened by the same method checked within limits that were sufficiently close for test purposes. No cast cutter was found to give results comparable to standard high-speed steel refined by suitable working. Cutters hardened by patented or salt-bath processes did not give results comparable to standard high-speed steel hardened by the open-fire method.

Non-Deforming Steels require Care. W. P. Eddy. (Iron Age, 1928, Vol. 121, Feb. 16, pp. 468-470). There are two important classes of non-shrinking oil-hardening tool steels. The first and older type contains usually 0.85 to 1 per cent. carbon, and 1.50 to 1.75 per cent. manganese; some brands also have 0.15 to 0.25 per cent. vanadium. The second type is a later development of the simple manganese oil-hardening steel. It contains the same amount of carbon, but about $\frac{1}{2}$ per cent. less of manganese than the older type, and has approximately 0.5 per cent. each of chromium and tungsten; some brands of this type also contain a small amount of vanadium. The chrome-tungsten type is slowly displacing the straight manganese type. The method of heat-treating these steels to prevent cracking, warping, and soft or brittle skin, and to get the desired hardness and size, is discussed by the author.

On the Double Carbide of High-Speed Steel. A. Westgren and G. Phragmén. (Transactions of the American Society for Steel Treating, 1928, Vol. 13, Apr., pp. 539-552). By means of X-ray examination the authors have proved the identity of the carbide constituent of high-speed steel. This entirely, or at least mostly, consists of an iron-tungsten carbide, which is neither an iron-substituted tungsten carbide nor a tungsten-substituted cementite, but a double carbide in the proper sense of the word. It has a face-centred cubic lattice, and probably there are 112 atoms in the elementary cube. Attempts to produce synthetically an alloy consisting entirely of this carbide failed, but almost homogeneous melts were produced. Microscopic investigation and chemical analysis showed that the composition of the carbide corresponded to the formula $\text{Fe}_4\text{W}_2\text{C}$. X-ray photographs of iron-molybdenum-carbon alloys have proved the existence of an iron-molybdenum carbide analogous to that of the iron-tungsten carbide of high-speed steel.

High-Speed Steel. J. S. G. Primrose. (Royal Technical College Metallurgical Club Journal, 1927-28, No. 6, pp. 29-34). The metallography and heat treatment of high-speed steel are discussed.

Alloy Steels, their Manufacture, Properties, and Uses. H. C. H. Carpenter. (Journal of the Royal Society of Arts, 1928, Vol. 76, Jan. 27, pp. 250-271; Feb. 3, pp. 278-297; Feb. 10, pp. 302-322; Feb. 17, pp. 326-348). After an historical introduction, the author gives some production statistics, and then discusses the principal alloying metals, and the effects of additions on the inversions of steels and, consequently, on their microstructures. He then considers the classification of steels (a) according to their thermal change points, and (b) according to their microstructures. He then deals in detail with the various alloy steels: tungsten, chromium, manganese, nickel, chrome-nickel, silicon, chrome-vanadium, tungsten-chromium, tungsten-chromium-vanadium, and heat-resisting steels; he indicates the effects of the alloying elements on the inversions of the steels; and describes their manufacture, properties, and uses.

A Study of the Physical Properties of Electrolytic Cobalt and Its Alloys with Iron. W. C. Ellis. (Rensselaer Polytechnic Institute, Engineering and Science Series, 1927, No. 16). The previous work on the properties of cobalt and the iron-cobalt system is reviewed and the preparation and properties of electrolytic cobalt are described. The following properties of the iron-cobalt system were also studied: (1) forgeability and metallography; (2) the X-ray crystal structure; (3) electrical conductivity from liquid air temperature to 1000° C.; (4) the thermo-electric properties; and (5) the magnetic flux densities and permeabilities in low and medium fields. The report concludes with a bibliography of the more important published researches on the subject. The entire range of iron-cobalt alloys prepared from electrolytic cobalt and electrolytic iron by melting *in vacuo* can be forged hot. The microscopic examination reveals an unbroken series of solid solutions. The crystal structure analysis of the series indicates three types of structures stable in different ranges. These structures are hexagonal close-packed, face-centred cubic, and body-centred cubic. No evidence of compound formation was found. The electrical resistivities of the alloys in the middle of the series are lower than the values for the pure components. This condition persists over a wide range of temperatures. The thermo-electric force of the system iron-cobalt becomes increasingly negative as the cobalt content is increased. The alloys in the middle of the series, however, occupy an anomalous position. No generalisations were deduced in regard to the magnetic behaviour of the iron-cobalt system. However, all of the materials studied were ferro-magnetic. The alloy FeCo possesses the highest saturation values in medium fields. The evidence would indicate that the anomalous conductivity characteristics in the iron-cobalt system are not due to compound formation, but to a peculiar solid solution.

Comparative Test of the Behaviour of Unalloyed and Alloyed Boiler Plates at High Temperatures and with Regard to Ageing and Recrystallisation. F. Körber and A. Pomp. (Mitteilungen aus dem

Kaiser-Wilhelm-Institut für Eisenforschung, 1927, Vol. 9, No. 22, pp. 339-400; Stahl und Eisen, 1928, Vol. 48, May 24, pp. 681-689). Complete mechanical tests over a range of temperatures were carried out on fourteen boiler plates, ten unalloyed and four alloyed with 3 and 5 per cent. of nickel. The behaviour towards ageing was determined on both naturally and artificially aged specimens. The tendency towards coarse recrystallisation, and its effect on the mechanical properties and on the structure, were examined. The results are completely set out in 37 tables, amplified by 52 diagrams and 74 micrographs, from which it may be seen that the harder plates, particularly the nickel alloy plates, behaved better than the low-carbon plates with regard to high temperature, susceptibility to ageing, and tendency to coarse recrystallisation.

Armco Ingot Iron. R. L. Kenyon. (Transactions of the American Society for Steel Treating, 1928, Vol. 13, Feb., pp. 240-269, Mar., 435-472). The paper includes a description of Armco iron, its chemical analysis, its microstructure after various treatments, and the effect of mechanical work and heat treatment on its various physical properties. These data are given for the material in the form of hot-rolled and cold-rolled bars and shapes, plates, sheets, and wire. The tests reported include tension, compression, shearing, impact, hardness, and fatigue tests of various kinds. A bibliography of literature on the subject is appended to the paper.

Staybolt Materials Compared. (Iron Age, 1927, Vol. 120, Dec. 29, pp. 1785, 1829-1830). The tabulated results are presented of two independent investigations of the properties of staybolt materials. The first was carried out in the laboratory, and in the second the materials were put through processes of manufacture and driven in boilers. In the first investigation, tests were made on 1-in. bars as received and after annealing, the materials being hot-rolled low-carbon steel; hot-rolled staybolt iron; hot-rolled staybolt steel; hot-rolled staybolt steel containing 2 per cent. nickel; and a fairly low carbon 3.5 per cent. nickel steel. The results show the best combination of qualities is to be had in 2 per cent. nickel staybolt steel with very low carbon. The yield point and ultimate tensile strength, while not the highest, are sufficiently high; the impact value is on the average more than twice as great as for any other material, and the endurance limit is only exceeded by the 3.50 per cent. nickel steel. In the second investigation the materials used were three staybolt steels of varying composition and one staybolt iron. Tensile tests were carried out on specimens before any work was done on them, at different stages during manufacture, and finally five staybolts were picked at random and tested after giving them the same treatment as driven bolts. Of the steels tested one contained about 0.25 per cent. nickel and a small amount of chromium, one contained over 2 per cent. nickel, and one contained 0.50 per cent. chromium and a small proportion of nickel.

The steel containing chromium showed slightly better strength, but the elongation and reduction of area were diminished by the working, while the 2 per cent. nickel steel showed an increase in these properties. The conclusions drawn from both investigations are that steel containing about 2 per cent. nickel is a superior product for staybolt purposes.

Air-Hardening Rivet Steels. H. K. Herschman. (United States Bureau of Standards, 1927, Technologic Paper No. 358). This report describes an investigation of a series of alloy steels possessing air-hardening qualities for the purpose of determining their applicability for rivets. The steels selected included for the most part those of the chromium-nickel series and some containing additions of manganese and molybdenum. In addition to the variation of alloy content, the carbon content was also varied. The steels were tested in the finished rivet form as well as in other ways, as, for example, the tensile test. The results pointed to the shear test as the best single indication of the true value of any particular steel for rivet use. From this test a fair prediction, at least, could be made of the ballastic and impact properties of the various steels used. The regulation of the carbon content is a very important factor in the make-up of alloy rivet steels. Small variations appear to affect materially the physical properties. There is an optimum carbon content for each particular alloy content which, it appears, can readily be determined by a shear test, together with hardness determination. The optimum carbon content for a 3.5 per cent. nickel, 1.5 per cent. chromium steel, was found to be about 0.20 per cent. Steels containing a total of 4 to 6 per cent. of the alloying elements, chromium and nickel, were found to produce excellent rivets. However, equally good results were obtained with steels of lower total alloy content by using, in addition to chromium and nickel, the elements molybdenum and manganese.

The Building of Containers for Severe Service. T. M. Jasper. (Industrial and Engineering Chemistry, 1928, Vol. 20, May, pp. 466-470). A discussion of the design, construction, and testing of large containers used in the chemical, oil, and other industries. These vessels are required to carry increasingly higher pressures, withstand greater variations of temperature, and resist the corrosion effects of a greater variety of conditions as compared with the requirements of a few years ago. An important factor in the selection of materials is the strength of steel at high temperature. Short-time tests give very erroneous results, and it is believed that the following method of testing is the only safe one for determining the strength of metals under long-time working conditions above 500° F. Ten specimens of the steel are prepared. The first is introduced into a lead bath in a furnace and under a stress that will cause failure. The length of time it takes the specimen to fail at a definite temperature indicates at

what stress for this temperature the next specimen should be introduced into the testing machine. The results of time and stress failures are plotted and a curve results which becomes asymptotic to the time ordinate. This asymptotic line indicates the long-time ultimate strength of the steel.

Steel for Aircraft Construction. E. A. Richardson. (American Institute of Mining and Metallurgical Engineers, 1928, Technical Publication No. 94). The purpose of this paper is to point out the many problems which have a distinct bearing on the choice of materials for aircraft construction. The general principles of airplane construction and design are discussed preparatory to a discussion of the application of metal. This is followed by a discussion of practice in airplane construction, manufacturing methods and materials, the relative advantages of wood and metal, and the possibilities of all-metal construction. The paper concludes with a brief discussion of suitable steels.

Aircraft Metallurgy. H. C. Knerr. (Transactions of the American Society for Steel Treating, 1928, Vol. 13, May, pp. 723-758). The subject is discussed under the following headings: choice of materials, specifications for purchase and inspection, properties of the principal metals used in aircraft construction, processes of machining, forming, riveting, welding, brazing, foundry practice, and corrosion prevention. Some causes of failure and their prevention are dealt with. An example is given of the results of the application of correct principles in reducing the rejection of metal parts during fabrication.

Chrome-Molybdenum Steel in Airplane Construction. (Iron Age, 1928, Vol. 121, Apr. 19, pp. 1076-1078). The steel used almost exclusively by the United States Army has the following analysis: Carbon, 0.25 to 0.35; manganese, 0.40 to 0.60; chromium, 0.80 to 1.10; and molybdenum, 0.15 to 0.25 per cent. This material has excellent welding and air-hardening properties, and a tensile strength of 95,000 lb. per sq. in. can be obtained after cooling from a welding heat. The results obtained on plain butt welds are tabulated. The normalised steel has an ultimate tensile strength and elongation equivalent to that obtained by quenching in oil and tempering at 1200° F., but has a lower yield point. Recent investigations of chrome-molybdenum sheet steel have indicated that it is even superior to chrome-vanadium steel. Normalised material can be bent 180° over a radius equal to the thickness of the sheet without cracking. Annealing the material or quenching and tempering at 1200° to 1300° F. increases the workability.

Alloy Bearings Applied to Trains. F. C. Langenberg and C. McKnight. (Iron Age, 1928, Vol. 121, Jan. 12, pp. 130-131). Attention

is drawn to the use of nickel-molybdenum steels for anti-friction bearings on railroads, and the authors describe the properties of steel containing 1·14 per cent. nickel, 0·14 per cent. molybdenum, and 0·305 per cent. carbon, after being subjected to different heat treatments. The nickel-molybdenum steel in the higher carbon ranges gives a high resistance to impact as compared with other compositions when the same physical properties as regards elastic limit and tensile strength are obtained. There is no rapid decline in elastic limit at temperatures above atmospheric.

The Effect of Manganese on the Properties of Low-Carbon Steels.

J. A. Jones. (*Metallurgist*, 1927, Oct. 28, pp. 151-154; Nov. 25, pp. 166-169; Dec. 30, pp. 186-187; *see also* this Journal, p. 633). Experiments made on crucible steels, commercial plates, and high elastic limit structural steels indicate the advantage of securing high-tensile properties by the adoption of a high manganese content rather than by high carbon only. The amount of manganese that may be advantageously added is limited to a figure which varies with the carbon content; thus 1·8 per cent. of manganese may be added with 0·2 per cent. of carbon, but the maximum falls to 1·5 per cent. of manganese when the carbon rises to 0·35 per cent. Small specimens of ordinary mild steel, with not more than 0·25 per cent. of carbon or 0·7 per cent. of manganese, oil-quenched from the normalising temperature, may have tensile properties even superior to those of normalised high-manganese steels, but the fatigue properties are not improved to the same extent by oil-quenching. An alternative to normalising is the careful control of the finishing temperature of rolling.

The Properties of Nickel Steels, with Special Reference to the Influence of Manganese. J. A. Jones. (Paper read before the Iron and Steel Institute, May 1928: this Journal, p. 295).

Nickel in Armaments. G. Charpy. (*Revue de Métallurgie, Mémoires*, 1927, Vol. 24, Dec., pp. 715-721). The author discusses the part played by nickel in the development of projectiles, cannon, and, particularly, armour plate.

Nickel in the Automobile and Aviation Industries. L. Guillet. (*Revue de Métallurgie, Mémoires*, 1927, Vol. 24, Dec., pp. 722-729). The author discusses the properties of nickel steels which have found particular application in the manufacture of motor cars and aeroplanes.

On the Determination of the Heterogeneous Field in the System Iron-Nickel. K. Honda and S. Miura. (*Science Reports of the Tôhoku Imperial University, Sendai*, 1927, Vol. 16, pp. 745-753; *Transactions of the American Society for Steel Treating*, 1928, Vol. 13, Feb., pp. 270-281). The authors have determined the heterogeneous field in the

iron-nickel alloys by dilatometric analysis. By the application of the law of depression of freezing point, the lowering of the A_3 point of iron by the addition of nickel was calculated and found to agree with the observed data. The variation of the coefficient of expansion with the concentration in the system iron-nickel is discussed in the light of the structural change of the system.

Alloys with High Contents of Nickel and of Chromium. P. Chevenard. (*Revue de Métallurgie, Mémoires*, 1928, Vol. 25, Jan., pp. 14-34). The author discusses the properties and application of nickel-chromium alloys and alloys of these metals with iron.

The Anomalies of Nickel Steels and their Applications. C. E. Guillaume. (*Revue de Métallurgie, Mémoires*, 1928, Vol. 25, Jan., pp. 35-43). The author relates some of his experiences during his search for a material suitable for replacing platinum alloys in the construction of standard metres, and discusses in this connection the anomalies of the expansion of invar (36 per cent. nickel). Other uses to which iron-nickel alloys of various compositions are put (platinite for sealing leads into electric lamps, nickel 42 to 44 per cent., coefficient of expansion similar to glass; a special steel for use in conjunction with brass for compensating chronometers; elinvar, the elasticity of which is invariable, &c.) are described, and the phenomena on which they are based are discussed.

Status of the Development of High-Duty Structural Steel in Hungary. E. H. S. Gállik. (*International Congress for Testing Materials, Amsterdam*, 1927, Vol. 1, 83-102).

The Constitution of the Iron-Silicon Alloys. M. G. Corson. (*American Institute of Mining and Metallurgical Engineers*, 1928, Technical Publication No. 96). A review is given of the work of previous investigators. The constitutional features of the iron-silicon series were investigated by the author by means of electric resistivity, Rockwell hardness, and metallographic tests, followed by X-ray analysis. A study was also made of the ductility and malleability of iron-silicon alloys, their resistance to corrosion, and the influence of carbon. The paper concludes with a discussion of the influence of other metallic and non-metallic additions.

The Mechanical Properties of Iron-Silicon Alloys. T. Meierling and W. Denecke. (*Die Giesserei*, 1928, Vol. 15, Apr. 27, pp. 381-384).

The Temper Brittleness of Soft and Semi-Hard Steels. I. Fetschenko-Tehopivski (*Zeitschrift des Oberschlesischen Berg- und Hüttenmännischen Vereins zu Katowice*, 1927, Vol. 66, Sept., pp. 548-555, Oct., pp. 624-638).

Investigation of Brittleness of Annealed Chrome-Nickel Steel. R. Wijkander. (*Jernkontorets Annaler*, 1928, No. 1, pp. 1-19).

Investigation of the Brittleness of Some Annealed Chrome-Nickel Steels and One Nickel Steel. B. Palmgren. (*Jernkontorets Annaler*, 1928, No. 1, pp. 20-25).

Physical Properties of Several Chromium-Aluminium and Chromium-Nickel-Aluminium Steels. V. O. Homerberg and I. N. Zavarine. (*Transactions of the American Society for Steel Treating*, 1928, Vol. 13, Feb., pp. 297-304). The affinity of aluminium for nitrogen in the ammonia case-hardening process has resulted in the manufacture of special alloy steels containing aluminium together with chromium or chromium and nickel. The subjection of these steels to the action of ammonia gas at a comparatively low temperature results in the production of a very hard surface without deformation of the material and without any subsequent heat treatment. The authors present the results of an investigation of the physical properties of two chromium-aluminium steels and one chromium-aluminium-nickel steel. There is no reason to believe that these steels are suitable only for nitrided articles. They should be considered as a valuable addition to the class of strong structural alloy steels and should find application for such purposes.

Alloy Steel for Boiler Construction. C. McKnight. (*Transactions of the American Society for Steel Treating*, 1928, Vol. 13, Apr., pp. 638-658). The author deals with the use of nickel steel for boiler construction, and presents the results of tests showing the advantages offered by this material. The paper includes a list of 21 references to literature on the subject.

Alloy Steels. B. Stoughton. (*Transactions of the American Institute of Mining and Metallurgical Engineers*, 1927, Vol. 75, pp. 497-525). The constitution of a number of ferrous alloys is shown by means of equilibrium diagrams prepared by different authorities.

Chromium Steel Rails. T. Swinden and P. H. Johnson. (Paper read before the Iron and Steel Institute, May 1928: this Journal, p. 611).

Superficial Cracking of Rails in Service. A. Portevin. (*Revue Générale des Chemins de Fer*, Sept. 1927, pp. 263-275). The author describes the methods to be adopted in the examination of railway rails, with a view to detecting fissures and cracks which may have occurred in the course of manufacture or may be due to the cold-working effect of the traffic passing over them.

Superficial Transverse Fissures in Rails. H. Viteaux. (*Revue de Métallurgie, Mémoires*, 1927, Vol. 24, Sept., pp. 485-495; Oct., pp. 601-618; Nov., pp. 671-682). The importance of transverse fissures in rails in France was first brought to light by experts who investigated the railway accident at Grisolles in 1908. A rail situated over an inspection pit was subjected to wheel-slip at the moment of starting of trains, and so had been severely cold-worked; the cold-work gave rise to the formation of cracks, and these were the cause of the rupture of the rail. Experiments to show exactly how the cracks developed, and to indicate, if possible, the means of preventing, or at least minimising, their occurrence, are described. Heavy mineral trains were run over test rails of various types of steel in various conditions of heat treatment, and wheel-spin was induced in the engine wheels by applying the brakes to the trucks. The wheel-spin varied from "gentle," caused by greasing the rails, to "severe," when the engine was brought to rest on the test rails with its wheels still revolving. Heat treatment of the rail is the best means of preventing fissuration.

Concerning the Superficial Fissuration of Rails in Service. (*Revue de Métallurgie, Mémoires*, 1928, Vol. 25, Mar., pp. 169-172). This consists of observations by M. Sabouret on the preceding article, and the author's reply to them.

Inverted Macrostructure in Certain Makes of Rails. E. Decherf. (*Revue Universelle des Mines*, 1928, Vol. 17, Mar. 15, pp. 269-277). In the ordinary way, the impurities and inclusions are found collected together in the heart of a rail; the author describes cases, however, in which the Baumann test shows that "an inverse macrostructure" has been produced. Tests made to determine the effect of this phenomenon on the physical and mechanical properties of the rail are described. It is suggested that this peculiarity is due to the ingots having been stripped and rolled too early.

Endurance and Other Properties of Rail Steel. J. R. Freeman, jun., R. L. Dowdell, and W. J. Berry. (*United States Bureau of Standards*, 1928, Technologic Paper No. 363). A series of tests on the properties of rail steel has been carried out, with particular reference to their resistance to repeated stress. Eleven heats of steel were studied, some of which were cast in standard moulds and others in sink-head moulds. The endurance limit of steel from 100-lb. rails was found to vary from a minimum of approximately 41,000 lb./in.² to a maximum of approximately 59,000 lb./in.², and the endurance ratio from 37 to 44 per cent. In general, rails rolled from sink-head ingots had higher endurance limits. It was found that the endurance limit of rail steel is decreased by overstressing, and may be increased by understressing. A method is suggested whereby it may be possible

to determine if rail steels in service are subjected to stresses greater or less than their endurance limits.

Notes on the Spark Testing of Steel. G. M. Enos. (Transactions of the American Society for Steel Treating, 1927, Vol. 12, Dec., pp. 976-981). The author describes the technique of spark testing, and indicates the spark characteristics typical of a selected group of irons and steels.

Thermal Expansion of Alloys of the "Stainless Iron" Type. P. Hidnert and W. T. Sweeney. (United States Bureau of Standards, 1928, Scientific Paper No. 570). The paper gives results on the linear thermal expansion of nine samples of stainless iron which were obtained from various sources. The chromium content of these samples varied from 11.9 to 16.4 per cent. and the carbon content from 0.09 to 0.13 per cent. Expansion determinations were made over various temperature ranges between room temperature and 1000° C. Transformation regions were located on some of the samples. The expansion curves of all of the samples are shown and discussed. The data relating to the critical regions indicate that an increase in the chromium content of stainless iron generally causes a slight increase in the temperature at which the transformation occurs on heating. The contraction during the transformation on heating decreases with increase in the chromium content. A table gives average coefficients of expansion derived from data on all samples of stainless iron. The coefficient of expansion increases gradually with temperature.

Expansion Characteristics of Low-Expansion Nickel Steels. H. Scott. (Transactions of the American Society for Steel Treating, 1928, Vol. 13, May, pp. 829-847). The author describes a differential expansion test apparatus with which continuous expansion curves can be made from liquid air temperature to 1110° F. (600° C.). Expansion curves of a number of synthetic iron-nickel alloys and commercial nickel steels containing from 30 to 50 per cent. nickel were taken. The characteristic expansion properties of these alloys—namely, minimum coefficient of expansion, inflection temperature, and temperature range of the low coefficient—were tabulated, and these data plotted against nickel content to show the best coefficients of expansion and the temperature range over which they are available for alloys of any nickel content which contain the usual impurities. The detrimental effect of manganese and silicon on the expansion properties is shown and the values of these properties estimated for 0 per cent. manganese and silicon. The advantage of cold-working to reduce the coefficient of expansion is confirmed.

Dilatometric Analysis of Steel and some Results of Dilatometric Heat Treatment. R. W. Woodward and S. P. Rockwell. (Transactions of the American Society for Steel Treating, 1928, Vol. 13, May, pp. 795-812). The authors obtained dilatometric curves of some commercial

steels, and from these certain fundamental dilatometric constants and transformation temperatures were secured. From these constants it is proposed to classify steels according to their proper quenching medium, although further study is necessary to set the limits for such a classification. Heat treatment taking advantage of thermal hysteresis is discussed, and a means is shown for further increasing hysteresis and securing the benefits of still lower quenching temperatures for certain steels. Normal oil-quenching steels when treated to take advantage of thermal hysteresis may be brine-quenched with superior results. Quenching at the completion of the transformation or point of re-expansion, produces the best properties. The quenching point for this treatment can be readily obtained by the automatic signal device on the dilatometer. When greater depth of hardness is essential other fixed points on the dilatometric curve may be used at the sacrifice of toughness and grain-size.

Influence of an Addition of Chromium on the Internal Friction of Reversible Ferro-Nickel. P. Chevenard. (*Comptes Rendus*, 1927, Vol. 185, Nov. 21, pp. 1130-1132). The addition of chromium to reversible ferro-nickels of the invar group extends the range of temperature in which internal friction is relatively feeble. This effect and its relation to an anomaly previously recorded are shown in a three-dimensional diagram.

Thermal Expansion of Cobalt-Nickel, Cobalt-Iron, and Iron-Nickel Alloys. A. Schulze. (*Physikalische Zeitschrift*, 1927, Vol. 28, Oct. 15, pp. 669-678).

Measuring a Billionth of an Inch. P. C. Jones. (*Heat Treating and Forging*, 1927, Vol. 13, Dec., pp. 482-483). The extensometer described depends for its action upon the reflection of a beam of light. Between the light source and the movable reflecting mirror a grating is placed, the image of which is reflected on to an extension of the same grating. When the image coincides with the second part of the grating the light gets through and operates a photo-electric cell, but any tilting of the mirror due to expansion or contraction of the test-piece alters the register of the image and grating and the amount of light falling on the photo-electric cell is diminished or completely shut off. The cell actuates a sensitive galvanometer so that the readings are still further subdivided. A few notes on the magnetic properties of permalloy are briefly mentioned.

SPECIFICATIONS.

British Standard Specifications and Sections for Tramway Rails and Fishplates. (British Engineering Standards Association, 1927, Report No. 2).

British Standard Specification for Steel Bars suitable for Automatic and Turret Lathes. (British Engineering Standards Association, 1927, Report No. 32).

British Standard Specification and Sections for Steel Fishplates for British Standard Bull-Head Railway Rails (for Rails from 70 lb. to 100 lb. per yard inclusive) and for British Standard Flat-Bottom Railway Rails (for Rails from 25 lb. to 125 lb. per yard inclusive). (British Engineering Standards Association, 1928, Report No. 47).

British Standard Specification for Round Strand Steel Wire Ropes for Colliery Winding Purposes. (British Engineering Standards Association, 1928, Report No. 300).

British Standard Specification for White-Heart Malleable Iron Castings (not Applicable to Light Castings which are to be Subjected to Hydraulic, Steam, or Air Pressure Tests). (British Engineering Standards Association, 1928, Report No. 309).

British Standard Specification for Black-Heart Malleable Iron Castings (not Applicable to Light Castings which are to be Subjected to Hydraulic, Steam, or Air Pressure Tests). (British Engineering Standards Association, 1928, Report No. 310).

British Standard Specification for Grey Iron Castings, Grades A and C. (British Engineering Standards Association, 1928, Report No. 321).

British Standard Specification for the Quality of the Material for Colliery Cage Main Shackles and Bridle Chains. (British Engineering Standards Association, 1928, Report No. 322).

British Standard Specification for the Quality of the Material for Colliery Rope Capels or Sockets for Use in Hauling or Winding Men. (British Engineering Standards Association, 1928, Report No. 323).

Standard Bolt-Heads and Nuts. (American Machinist, European Edition, 1927, Vol. 67, Dec. 17, p. 747 ; Dec. 31, p. 825 ; 1928, Vol. 67, Jan. 7, p. 865). The standards for bolt-heads and nuts approved recently by the American Engineering Standards Committee are tabulated.

Tools and Tool Steel Specifications. E. S. Lawrence. (Heat Treating and Forging, 1928, Vol. 14, Jan., pp. 26-31, 37). The factors to be considered in specifying for the purchase of tool steels—chemical, physical, and microscopical—are discussed.

MAGNETIC AND ELECTRIC PROPERTIES OF IRON AND STEEL.

Magnetic Alloys Named and Defined. (Iron Age, 1928, Vol. 121, Feb. 23, pp. 534). The properties and composition of the following alloys in common use are briefly described: permalloy, hipernick, copernick, "A" metal, thermalloy, K.S. magnet steel, cobalterom, permanite, and nomag.

Testing Magnetic Sheet Steels. B. G. Churcher. (World Power, 1928, Vol. 9, Jan., pp. 15-21). The improved apparatus described, for testing magnetic sheet steel under alternating magnetisation, is specially designed for use in acceptance tests in connection with the purchase of sheet steel for making electrical plant. The conditions necessary for these tests to be commercially satisfactory are described. Errors which arise in the use of the apparatus are discussed and their magnitude assessed.

Some Principles Governing the Choice and Utilisation of Permanent Magnet Steels. R. L. Sanford. (United States Bureau of Standards, 1927, Scientific Paper No. 567). The addition of substantial percentages of cobalt to the composition of permanent magnet steels leads to markedly superior qualities. The cost of cobalt steels may be several times that of the older types, however, and their use is warranted only under certain circumstances. Criteria for the comparison of the quality of magnet steels are discussed, and the conditions under which the use of the more expensive steels is justified are outlined.

The Effect of Silicon on Tungsten Magnet Steels. J. Swan. (Paper read before the Iron and Steel Institute, May 1928: this Journal, p. 369).

A Method of Testing Iron by Means of a Magnetic Voltmeter. W. Wolman. (Archiv für Elektrotechnik (Aachen), 1928, Vol. 19, Jan. 25, pp. 385-404).

CONSTITUTION, STRUCTURE, CRYSTALLOGRAPHY.

Density of Hot-Rolled and Heat-Treated Carbon Steels. H. C. Cross and E. E. Hill. (United States Bureau of Standards, 1927, Scientific Paper No. 562). In this report are given density values for commercially pure and electrolytic iron, and a series of carbon steels, varying from 0.09 to 1.29 per cent. of carbon. Density values are given for these steels in the hot-rolled, annealed, quenched, and quenched and tempered conditions. Quenching was carried out in

water. The sections of the specimens and the quenching temperatures were varied with the carbon content; the smallest section and highest quenching temperature being used for the steel of lowest carbon content. After quenching the steels were tempered at successively higher temperatures up to 600° C. and density determinations made after each treatment. The average density of pure iron was found to be about 7.864 grm. per c.c. Carbon steels, as hot-rolled, show a gradual decrease in density with increasing carbon content up to about 1.3 per cent., and the values lie on or close to the straight line, which may be represented by the equation: $\text{Density} = 7.855 - 0.032 C$, where C is the percentage of carbon. Annealed carbon steels show a gradual decrease in density with increasing carbon content up to about 1.4 per cent., and the values lie on or close to the straight line which may be represented by the equation: $\text{Density} = 7.860 - 0.04 C$. Carbon steels (up to 1.30 per cent. carbon) decrease in density when quenched, due to the formation of martensite. The magnitude of this decrease rises with increasing carbon content, reaching a maximum at about 1 per cent. carbon, and then falls off slightly. Upon tempering the quenched steels gradually increase in density. A decrease in density is noted in the hyper-eutectoid steels when tempered at 225° C., and this may be ascribed to the tempering of retained austenite. Upon further tempering above 225° C. the density of all samples increased, ultimately approaching the density of the annealed steel upon tempering at 600° C. The greatest increase in density occurs upon tempering at 300° C.; the rate of increase then gradually falls off as the tempering temperature is raised to 600° C.

Rapid Determination of the Silicon Content of Ferro-Silicon by Means of the Density. M. Schwarz. (Chemiker-Zeitung, 1927, Vol. 51, Oct. 22, p. 815). The relation between the density of ferro-silicon at room temperature and its silicon content is shown by means of a curve.

Tempering Changes in Carbon Steels. R. Hay and R. Higgins. (Journal of the Royal Technical College, Glasgow, 1927, Dec., No. 4, pp. 62-76). The tempering changes which take place in quenched steels have been investigated by determining the Brinell hardness number, specific volume, yield stress, maximum stress, percentage elongation, and Charpy impact value of specimens which had been water-quenched from 1000° C., and tempered from room temperature to 650° C. at 25° C. intervals. Irregularities occur in the property-temperature curves at 100° C., 250° C., and 350° C. approximately. The change about 350° C. occurs over a wide range of temperature. It is suggested that the change at 100° C. is due to the decomposition of the solid solution of Fe_3C in α -iron. That this solubility is of appreciable importance is demonstrated by means of specific volume and Izod impact tests, which show that there is a marked solubility of Fe_3C in α -iron between 550° C. and 650° C. The change at 250° C.

is attributed to the decomposition of residual austenite in the quenched specimens. The 350° C. change is accounted for by the fact that all the remaining austenite does not transform immediately to martensite and then to troostite, but that the change is periodic and takes a certain time to go to completion.

On the Mechanism of Tempering of Steels. T. Matsushita and K. Nagasawa. (Science Reports of the Tōhoku Imperial University, 1927, Vol. 16, pp. 901-913. *See also* Journ. I. and S.I., 1927, No. 2, p. 311).

On a New Method of Quenching Steels in a High Temperature Bath. K. Honda and K. Tamaru. (Science Reports of the Tōhoku Imperial University, Sendai, 1928, Vol. 17, pp. 69-83). Steels were quenched in a salt bath heated to different high temperatures up to 570°, and their hardness and microstructures were examined. Between 20° and 150° the structure was always martensitic, above 150° troostite appeared from grain boundaries, and between 300° and 450° the structure was completely troostitic. In a range between 450° and 570° it was sorbitic. Below 120° quenching was always accompanied by cracks, but above it no cracks were observable. The hardness was at a maximum at a quenching temperature of 110° by virtue of the complete martensitisation of the steels. The sorbitic structure obtained by the present method was as strong as that obtained by the ordinary method of quenching and tempering. Thus the new method affords a means of obtaining the tempered structures by a single process without any risk of internal failure in steels, which might result during quenching.

The Constitution of Steel and Cast Iron. Section II., Part II. F. T. Sisco. (Transactions of the American Society for Steel Treating, 1928, Vol. 13, Feb., pp. 305-317). An elementary discussion of the annealing process. The structural changes taking place on heating and cooling are discussed.

The Constitution of Steel and Cast Iron. Section II., Part III. F. T. Sisco. (Transactions of the American Society for Steel Treating, 1928, Vol. 13, Apr., pp. 659-672). The author deals specifically with the structural changes taking place in annealing plain carbon steels, and in normalising and spheroidising.

On the Constitution and Properties of Hardened Steel. W. P. Sykes and Z. Jeffries. (Transactions of the American Society for Steel Treating, 1927, Vol. 12, Dec., pp. 871-904). The authors report the results of an investigation of the changes in hardness of freshly quenched steel, at above and below room temperature. In order to correlate hardness changes with changes in certain other properties some

electrical resistivity and volume measurements were made. Freshly quenched high-carbon steel when maintained near 0° C. does not change measurably in hardness for several hours. It hardens, however, if cooled below or heated above this temperature. The hardening on cooling is relatively independent of time, but dependent upon the temperature reached. This hardening is accompanied by an increase in volume, and is clearly due to austenite transformation. The hardening produced by heating above 0° C. is a time-temperature phenomenon. The higher the temperature the shorter the time required for a given small hardness increase, at least up to 100° C., and presumably up to a somewhat higher temperature. The capability of age-hardening above 0° C. is not lost by previous hardening produced by cooling below 0° C. In fact, the age-hardening at room and certain higher temperatures is greater after hardening by immersion in liquid oxygen. The maximum Rockwell "C" hardness values obtained on the carbon steels were 17.1 on a 1.23 per cent., and 70.2 on a 1.58 per cent. carbon steel.

A Contribution to the Theory of Hardening and the Constitution of Steel. Z. Jeffries. (Transactions of the American Society for Steel Treating, 1928, Vol. 13, Mar., pp. 369-404). A brief account is given of the life and work of E. D. Campbell, followed by an abstract of his paper bearing the above title (Journ. I. and S.I., 1914, No. II. p. 1). The subject is further discussed by the author. The conclusions are adopted that carbon steel austenite is gamma-iron containing carbon in atomic dispersion; that freshly formed carbon steel martensite is alpha-iron containing the carbon largely in atomic dispersion; that carbon steel martensite aged at room temperature or somewhat above that temperature contains myriads of particles of iron carbide. It is also shown that when acicular martensite forms, the orientations of the new alpha-iron grains have some relation to the orientation of the parent austenite. After concluding that the hardness of martensite can be attributed to grain refinement and carbon in solid solution, some researches are suggested which should help in estimating to what extent each of these factors contribute to the hardness of freshly formed martensite. Aged high-carbon steel martensites, containing precipitated carbide, are harder than freshly formed martensites from the same steels.

Theory of Hardening of Steel. K. Honda. (Archiv für das Eisenhüttenwesen, 1928, Vol. 1, Feb., pp. 527-533). The author previously put forward the theory that the A_1 transformation in carbon steels proceeds through an intermediate stage, martensite. He now extends his reasoning to show that two types of martensite exist, and that the A_1 transformation proceeds in the order, austenite— α -martensite— β -martensite—pearlite, each stage being marked by a change in the lattice. Both types of martensite have almost exactly the same lattice

as ferrite, the only difference being the presence of carbon atoms in the lattice spaces, which is one of the causes of the much greater hardness of the martensite. Other causes of the hardness of martensite are the fineness of grain and the internal stresses brought about by sudden quenching which produces a cold-working effect. Moreover, the carbon atoms in the lattice transmit their lines of force to six neighbouring iron atoms, thus acting as stiffeners in a square framework imparting increased strength to the whole. When the factors which cause hardness to increase are known, the calculation of their respective hardening values becomes easy; assuming that a hardened steel has a Brinell hardness of 680, and that of ferrite is 225, then the contribution of each factor to the total hardness is as follows:

Natural hardness of ferrite	.	.	.	.	225
Increase due to grain refinement	.	.	.	.	80
Increase due to internal stresses	.	.	.	.	150
Presence of carbon atoms in the lattice	.	.	.	.	225
					<hr/>
					680

The hardness of martensite is, in fact, more strongly affected by the arrangement and size of the crystal grains than by the atomic forces.

The Secondary Hardness of Alloy Steels. J. H. Andrew. (Royal Technical College Metallurgical Club Journal, 1927-28, No. 6, pp. 7-8). Certain steels, particularly alloy steels, when quenched from above the uppermost critical point and then tempered below the normal Ac_1 change, show an increment in their hardness figures. It is generally assumed that this increase is due to the austenite retained in the quenched specimen changing over to the martensitic condition, and it is inferred that the presence of austenite in the original quenched condition is an essential to the phenomenon. Nickel-chromium steels (3.6 per cent. nickel and 1.65 per cent. chromium) with a hyper-eutectoid carbon content have been shown (Journ. I. and S.I., 1920, No. I. p. 527) to exhibit secondary hardening propensities. A dilatation curve taken during tempering of the quenched specimen showed a gradual contraction on heating, which began at $400^\circ\text{C}.$, and the marked expansion which occurred on cooling at about $150^\circ\text{C}.$ The explanation given at the time was that the contraction was due to re-association of the dissociated carbide of iron, and that the expansion was due to the formation of martensite. A nickel-chromium steel which, after slowly cooling from $1300^\circ\text{C}.$, gave a completely non-magnetic sample and a microstructure which to all appearances was pure austenite was quickly heated up to and cooled from $1000^\circ\text{C}.$ in the dilatometer without any inflection in the dilatation curve being indicated. This same sample when slowly cooled from just above the Ac_1 change without previously heating to a high temperature gave the usual pearlitic characteristics.

The austenitic state would seem to depend upon the iron being just

completely saturated with carbon, so as to give a stable structure in which independent transformations of iron and carbide of iron, which go to build that structure, cannot occur. For any transformation to take place would seem to require the presence of either free iron or carbide of iron to bring it about. On quenching, the steel cools to ordinary temperature without undergoing any transformation. Tempering above 400° C. causes carbide of iron to be removed from solution, leaving a solid solution of a composition that under ordinary conditions of cooling gives rise to a critical change at 150° C. or thereabout. This transformation is the gamma-alpha change, and the net result is the formation of martensite. It is evident from the above theory that there must always be a tendency for the composition of any steel to alter so as to give rise to a solid solution of eutectoid composition which, having the greatest entropy value, must be regarded as having the maximum of stability within the temperature range of its existence. If, therefore, it is desired to obtain a steel which will remain uniformly austenitic, the correct method of attack would seem to lie in an attempt to vary the amounts of the alloying elements so that an alloy of true eutectoid composition will be produced which on normal cooling will give a homogeneous austenite.

Interatomic Forces in Metals and Alloys. R. F. Mehl. (American Institute of Mining and Metallurgical Engineers, 1928, Technical Publication No. 57). The importance of the study of interatomic forces in metals and alloys is pointed out. It is shown that data on compressibility and internal pressure furnish a basis for the analysis of the hardness of the pure metals. It is suggested that the electron distribution around the atom periphery probably introduces a slip-resistance factor in addition to that of the crystalline symmetry and the interatomic forces. The chemical attraction between unlike atoms in certain solid solutions has been approximately evaluated by means of measurements on compressibility and calculations of internal pressure. An analysis of the factors inducing hardness in certain completely isomorphous solid solutions has shown that only a small fraction of the total hardness can be ascribed to the attraction between unlike atoms, but it is pointed out that this attraction is largely contributory in producing slip-resistances of a purely crystallographic nature. It is suggested that the concept of atomic volume as applied to alloys has certain serious limitations, and that a complete analysis of the factors inhibiting slip should be made in terms of force fields.

Volume Changes in Steel due to Hardening and Annealing. W. Köhler. (Centralblatt der Hütten und Walzwerke, 1927, Vol. 31, Oct. 26, pp. 613-623).

Influence of Manganese and the Rate of Cooling on the Separation of Ferrite. P. Schafmeister and R. Zoja. (Stahl und Eisen, 1928,

Vol. 48, Mar. 8, pp. 312-313). The object of the investigation was to determine the carbon concentration at the eutectoid point in steels containing manganese in percentages rising to 3 per cent., noting at the same time the influence of the rate of cooling on the ratio of the ferrite to the pearlite. Since the position of the eutectoid point could not be precisely determined by plotting heating and cooling curves, the authors made use of the microscopic method. Three series of steels with a manganese content of 1.1, 2.1, and 3.1 per cent. and carbon ranging from 0.15 to 0.80 per cent. were examined at cooling rates of 10°, 20°, 60°, and 240° per hour, and also during cooling in air. The dependence of the ferrite on the carbon content follows not a straight line, but curved lines for the closer study of which in manganese steels the carbon must be estimated by microscopic methods. The amount of ferrite decreases with increasing rate of cooling or with increasing manganese, and the influence of the cooling rate increases with increasing manganese. The carbon of the eutectoid point amounts to 0.71 with 3.1 per cent. manganese, to 0.77 with 2 per cent. manganese, and to 0.83 with 1 per cent. manganese. The eutectoid carbon diminishes regularly with increasing manganese.

Segregation of Dissolved Elements and its Influence upon Carbon Distribution in Steel. E. G. Mahin and H. J. Dillon. (Transactions of the American Society for Steel Treating, 1927, Vol. 12, Dec., pp. 905-920). Theories that have been advanced to explain the common coincidence of non-metallic inclusions and pro-eutectoid ferrite or cementite in annealed steels are discussed. Further support is offered to the view that localised contamination of microscopic portions of metal by the inclusion is responsible, in large measure, for premature precipitation of the pro-eutectoid phase, thus starting local crystallisation of this phase. In addition, the metal in immediate contact with the inclusion is weakened, in most cases, by the contamination. It is suggested that this localised weakness may have much to do with fatigue failures.

On the Latent Heat of Fusion and the Heat of Transformation of Some Metals. S. Umino. (Science Reports of the Tôhoku Imperial University, Sendai, 1927, Vol. 16, pp. 775-798). The heat contents of manganese, thallium, carbon steels containing 0.57 per cent., 0.94 per cent., 1.16 per cent. carbon, and of pig iron containing 4.31 per cent. carbon and 1.11 per cent. silicon have been measured at high temperatures by the differential calorimetric method. From these results both the mean and true specific heat have been deduced, and the mean value of the heat of the Ac transformation in cementite has been found to be 9.72 cal. The heats of two transformations in manganese and that of thallium have been found to be 2.88, 4.53, and 0.60 cal., respectively. The latent heat of fusion of manganese, thallium, and pig iron have been found to be 64.8, 3.67, and 46.63 cal., respectively.

On the Heat of the A_2 and A_3 Transformations in Carbon Steels. S. Umino. (Science Reports of the Tôhoku Imperial University, 1927, Vol. 16, pp. 1009–1030). The author has measured the heat contents of carbon steel containing 0.040, 0.135, 0.270, 0.350, and 0.770 per cent. of carbon at high temperatures. From the results both the mean and specific heat were deduced, and it was found that the A_2 transformation in pure iron takes place in a range of about 140°C . The heat of this transformation was found to be 3.65 cal. per unit mass. This heat decreases as the carbon content increases. The rate of change of the A_3 transformation is a function of temperature. For a specimen of the size used in the investigation, it required more than 17 minutes to complete the transformation at 930°C ., and this transformation heat in pure iron was found to be 5.35 cal. per unit mass.

The Surface Tension of Molten Metals with a Determination of the Capillary Constant of Copper. E. E. Libman. (Illinois University, Engineering Experiment Station, 1928, Bulletin No. 173).

Studies of Recrystallisation in Steel for Transformer Sheets. M. von Moos, P. Oberhoffer, and W. Oertel. (Stahl und Eisen, 1928, Vol. 48, Mar. 29, pp. 393–403). For the purpose of studying the recrystallisation, melts were made in a Héroult furnace and cast into ingots of 300 kg. of the following composition: Carbon 0.05, silicon 4.07, manganese 0.08, phosphorus 0.007, and sulphur 0.006 per cent. The ingots were rolled into billets 18 mm. square. Eight series of tests were made at annealing temperatures ranging from 500° to 1200°C ., with an annealing period of 1 hr., and each series was subjected first to deformation by compression, the amount of deformation ranging in seven successive stages from 5 up to 50 per cent. Another series of eight tests was made under similar conditions, except that the annealing period at the different ranges was prolonged to 4 hrs. Recrystallisation set in at 700° to 800°C . in the specimens with deformation from 5 to 15 per cent., and at 600° in those subjected to deformation ranging from 20 to 50 per cent., and it proceeded according to the general laws of recrystallisation, though the ranges at which the phenomena occurred were pushed several hundred degrees higher up the scale, in the case of these high silicon steels. A critical range of deformation did not appear to exist. It was observed that besides the old crystal boundaries, the slip crystals appeared to be the nuclei from which recrystallisation proceeded to grow. The crystal growth on annealing at different temperatures and periods is shown by means of ingenious diagrams to range from 0 to 1,000,000 μ^2 in area.

Properties of Very Large Iron Crystals. T. B. Focke. (Thesis presented to the Faculty of Sciences of the University of Nancy, 1928, pp. 1–124). The subject is dealt with under the following heads: A study of the methods for obtaining large crystals; metallographic examination of the crystals; resistance of large crystals to tensile

stress and their deformations under stress; the resistance of large crystals to torsion and their deformations under torsion; study of the properties of large crystals after quenching at 800°C . in cold water; corrosion tests of large crystals and a study of the corrosion figures; brittleness of large crystals at the temperature of liquid air; the formation of nitrides on heating large crystals in ammonia to about 600°C . A list of the reagents used in the investigation is given, and a bibliography of the literature on the subject is appended.

The Crystallisation and Structure of Metals and Alloys. A. Portevin. (Bulletin de la Société Chimique de France, 1927. Reprint, pp. 1-27). In this lecture the author discusses the genesis of the structure—that is to say, the initial structure of solidification which influences all forms of structure due to subsequent treatment, the effect of deformations produced by cold-working, the effect of reheating or annealing after deformation, and the effect of allotropic transformations as exemplified in iron and mild steels.

The Behaviour of a Single Crystal of α -Iron subjected to Alternating Torsional Stresses. H. Gough. (Proceedings of the Royal Society, 1928, A., Vol. 118, pp. 498-534). The object of the investigation was to obtain information relating to the mechanism of deformation and failure of a single crystal of α -iron subjected to alternating torsional stresses. It has been shown previously that this type of straining action may produce complete fracture while the total distortion of the specimen as a whole remains extremely small, or even inappreciable. A large number of failures of modern machines have been of this kind. Careful observation of the slip bands was employed to relate the mechanism of deformation with the crystal structure and the applied stressing system.

Twin-Like Crystals in Annealed α -Iron. H. O'Neill. (Paper read before the Iron and Steel Institute, May 1928: this Journal, p. 689).

Critical Points in Chromium-Iron Alloys. A. B. Kinzel. (American Institute of Mining and Metallurgical Engineers, 1928, Technical Publication No. 100). The author has devised a method which gives an accurate determination of the critical points from expansion-temperature curves of a suspended wire, a special telescopic dilatometer being used for the purpose, operated in connection with a special vacuum furnace. It was found that the chromium-iron loop runs from 0 to 12.2 per cent. chromium. Its upper boundary runs from 1400°C . to 900°C ., following an oblique hyperbola, and its lower boundary runs from 900°C . at 0 per cent. chromium to 900°C . at 12.2 per cent. chromium.

Constituents of Annealed Steel. J. J. Curran. (Iron Age, 1928, Vol. 121, Jan. 12, p. 134). The author presents photomicrographs

showing that prolonged annealing near the critical temperature will break up lamellar pearlite and materially soften the steel. Three micros show the formation of massive cementite in steel containing less than 0.10 per cent. carbon.

High-Temperature Treatments of Castings and Forgings as Evidenced by Core Drill Tests from Heavy Sections. W. J. Merten. (Transactions of the American Society for Steel Treating, 1928, Vol. 13, Jan., pp. 1-28). The author discusses the results of investigations conducted primarily to determine the correct thermal treatments for the improvement of grain structure of heavy section steel castings. The paper also includes a study of the limitations of the current practice of evaluating the physical properties of large steel castings and forgings from comparatively small coupon tests. Experimental data supported by microscopical analysis of the complete and partial refinement respectively of the grain structure of steel castings near the surface and the centre of section is given, and shows that considerably higher temperature and extended soaking periods are necessary for proper adjustment and alteration of grain structure to permit of the use of higher service stresses in the design of large-size electrical machinery. Suggestions for a recommended practice of heat treatment are given.

Grain Growth in Metals Caused by Diffusion. F. C. Kelly. (American Institute of Mining and Metallurgical Engineers, 1928, Technical Publication No. 89). The author has investigated grain growth in cold-rolled iron caused by the diffusion of chromium, silicon, tin, molybdenum, and manganese. Photomicrographs show the different forms of grain growth induced. Grain growth started at the surface of the samples by small grains of iron absorbing the diffusing material, and extended by migration of grain boundaries in the direction of the diffusing force. The latter term is introduced by the author, as he believes that the common laws of crystallisation do not completely account for the observations made in the paper. The passage of a group of atoms through a metal lattice appears to exert a powerful force on the lattice, sufficient to produce reorientation, and this force is termed the "force of diffusion."

Unusual Features in the Microstructure of Ferrite. H. S. Rawdon and T. Berglund. (United States Bureau of Standards, 1928, Scientific Paper No. 571). Ferrite sometimes shows in its microstructure evidence of the fact that the metal may exist in various allotropic forms. Two of these features, apparently related to the δ and γ forms of iron, can usually be associated with tiny inclusions distributed in such a manner as to record the grain structure which existed in the high-temperature allotropic conditions. In the α (ordinary) condition there often appears within the grains a "veining," which gives the metal a pseudo-fine-grained appearance. Ferrite stressed or forged

at a temperature close to the α - γ transformation shows veining exceptionally well. Additions of Al or Mn to iron had no pronounced effect on α veining, whereas ferrite containing Si in amount sufficient to suppress the transformation showed no veining. The ordinary mechanical properties of iron are affected little, if at all, by α veining; the δ network appears to be associated with the hot-shortness of iron. The real nature of α veining is still in question.

The Structural Forms of Meteoric Iron. R. Vogel. (Archiv für das Eisenhüttenwesen, 1928, Vol. 1, Mar., pp. 605-611). Many illustrations of the structure of meteorites are given. For comparison of the structure artificial alloys of similar composition were made, and it is shown that the changes brought about by heating resemble those which appear to have been produced in the meteorite.

Preparation of Aluminium Oxide for Final Polishing and the Preservation of Polished and Etched Surfaces. W. P. Fishel. (Transactions of the American Society for Steel Treating, 1927, Dec., Vol. 12, pp. 982-983). To prepare aluminium oxide, strips of aluminium are washed in alcohol and immersed in a 10 per cent. solution of mercuric chloride in water. When well covered with a thin coating of metallic mercury the strips are rinsed in water to remove any adhering mercuric chloride. They are then placed in a beaker of hot distilled water. The reaction should be vigorous, hydrogen being evolved and aluminium oxide formed. The beaker and contents should be set aside for a few days. Add water occasionally to replace that used up. If the action stops, it is necessary to reamalgamate the strips and proceed as before. Oxide prepared in this manner approaches the colloidal state in fineness and will remain suspended for several days. It contains, however, some finely divided mercury which gives it a dark colour. To remove the mercury, place in a tall vessel, and add enough water to form a thick suspension and agitate thoroughly to cause the particles of mercury to collect. After settling, the top portion may be drawn off, and is then ready for use. Polished and etched surfaces of specimens may be preserved for future examination by coating them with a transparent lacquer of the cellulose-base type. A suitable lacquer is made by removing the gelatine from photographic films and dissolving the remaining portion (clear celluloid) in acetone, to make a solution having the consistency of varnish.

On the Technique of the Metallographic Investigation of Very Hard Metallic Alloys. K. Schröter. (Zeitschrift für Metallkunde, 1928, Vol. 20, Jan., pp. 31-33; *abstract*, **Metallography of Ultra-Hard Metals** (Metallurgist, 1928, Mar. 30, pp. 43-44). There is now available a series of extremely hard metallic alloys, which may prove of importance for dies, cutting edges, and other purposes where great hardness is required. One group of these alloys is based on tungsten carbide,

with which other hard substances, such as molybdenum carbide, cobalt, cerium, titanium, &c., may be associated. Their microscopic examination is rendered difficult, for their hardness renders all usual polishing methods useless. The author's method of preparing specimens consists in first grinding a flat with a carborundum wheel having a soft matrix; the first polishing is then done with a horizontal rotating iron disc fed with coarse "bort" or diamond dust suspended in olive oil, and the final polish is attained by using finer bort on a disc covered with felt or cloth. The surface may then be etched if required.

Photomicrography and its Application to Mechanical Engineering. F. F. Lucas. (Paper read before the American Society of Mechanical Engineers, Dec. 5-8, 1927: *Mechanical Engineering*, 1928, Vol. 50, Mar., pp. 205-212). **New Methods in Photomicrography.** (Heat Treating and Forging, 1928, Vol. 14, Mar., pp. 277-281). The equipment of the Bell telephone laboratories for technical microscopy, including details of the ultra-violet microscope, is described, and the application of high-power metallography to the study of structures found in hardened steel is discussed.

A Résumé of the Development and Application of High-Power Metallography. F. F. Lucas. (International Congress for Testing Materials, Amsterdam, 1927, Vol. 1, pp. 123-156).

Illumination in Metal Microscopy. H. S. George. (*Journal of the Optical Society of America*, 1927, Vol. 15, Nov., pp. 295-304). Several types of apparatus are discussed, and an improved device is described.

Convenient Movable X-Ray Equipment. A. St. John. (*Heat Treating and Forging*, 1928, Vol. 14, Mar., p. 292). By enclosing the X-ray tube in lead, the usual lead-lined room is rendered unnecessary. Several portable sets are briefly described; they have the advantage that they may be transported to the work to be examined.

X-Rays—A New Tool in the Foundry. (*Iron Age*, 1928, Vol. 121, Mar. 8, pp. 655-656). Examples of the use of X-ray examination for the detection of hidden defects in castings are shown.

The Application of X-Rays to the Study of the Crystalline Structure of Metals. Sir W. H. Bragg. (*Proceedings of the Institution of Mechanical Engineers*, 1927, Vol. 2, pp. 751-775). The fundamental principles of this method of examining the structure of metals is discussed under the following headings: The fine structure of materials; the use of X-rays; regularity of natural structures; the diffraction phenomenon; the "powder" photograph; the structure of iron; a ring system characteristic of every substance; the effect of treatment on the form of the rings; the rotation photograph; the "fibre" photograph; and various examples of fibre structure.

High-Speed, High-Voltage X-Ray Diffraction Analysis of Metals.

A. St. John. (Transactions of the American Society for Steel Treating, 1928, Vol. 13, Mar., pp. 485-492). A quick and convenient method of X-ray diffraction analysis has been developed. It is a modification of the usual "pinhole" method using tungsten radiation at 200,000 v., as in radiographing castings, so that a powerful beam passes through $\frac{1}{8}$ in. of steel. If desired, entire sheets or formed articles can be mounted in the instruments, or specimens can be cut without affecting the portion to be examined. Exposures of 2 hrs. or less are sufficient. The method has been applied to brass, tin, and steel in the study of mechanical working, heat treatment, extrusion, ageing, and the effect of exposure to gases. Some typical results are illustrated.

X-Ray Study of the Structure of Quenched Steel.

N. J. Seljakow, G. V. Kurdumoff, and N. T. Goodtzow. (Revue de Métallurgie, Mémoires, 1928, Vol. 25, Mar., pp. 99-104). In the present article (Part I.) the authors review briefly the opinions expressed by previous investigators on the atomic structure of steel, and then describe the materials used in the present investigation, their composition, heat treatment and microstructure, and the method of study adopted. The diffuse character of the spectrographic lines given by a quenched steel having a martensitic structure was a feature which had previously prevented a successful determination of the problem under discussion, but by the arrangement of the Debye-Scherrer apparatus in the manner described by the authors this difficulty was overcome.

X-Ray Examination of Structural Materials.

W. P. Davey. (Paper read before the American Society of Mechanical Engineers, Dec. 5-8, 1928; Mechanical Engineering, 1928, Vol. 50, Mar., pp. 213-216). **Modern Researches on the Structures of Metals.** (Journal of the Franklin Institute, 1928, Vol. 205, Feb., pp. 221-228). In both papers the author reviews the uses to which X-rays may be put in investigating the properties of metals, and describes the atomic structures of iron and steels.

Using X-Rays to Inspect Materials for Internal Defects.

H. R. Isenburger. (Foundry, 1928, Vol. 56, Mar. 1, pp. 171-173; Iron Trade Review, 1928, Vol. 82, Jan. 26, pp. 264-266). A brief description of the methods used for the X-ray examination of metals.

HEAT-RESISTANT AND ACID-RESISTANT ALLOYS.**Heat-Resisting Steels. Part II.—Mechanical Properties.**

W. H. Hatfield. (Paper read before the Iron and Steel Institute, May 1928; this Journal, p. 573).

Heat-Resisting Alloys. W. Rohn. (Korrosion und Metallschutz, 1928, Vol. 4, Feb., pp. 25-28). The author describes a test for examining the rust-resisting properties of metals. The material is drawn into wire, and a length is coiled into an open spiral and supported on insulating rods at the bottom of a trough-shaped vessel. The passage of an electric current through the wire raises its temperature to the desired value; at the end of the test the rapid cooling of the wire causes some of the rust to fall off, and this is collected in the trough, and the rest is removed by stretching the wire out straight again. The wire is then re-coiled and the test repeated until the straightening process causes fracture. The stretching of the wire causes a considerable elongation. The quantities of rust which fall off and those which are mechanically removed are kept separate and are weighed after each test. The results obtained by this method with various heat-resisting alloys and with pure iron and nickel are recorded. Finally, the author gives examples of cementation boxes and enamelling grids made of heat-resisting alloys, and similar articles made of steel to show the superior durability or life of the former over the latter.

Heat-Resisting and Non-Corrodible Steels. S. A. Main. (Journal of the Institution of Aeronautical Engineers, 1927, Vol. 1, Aug., p. 5). The properties and uses of special heat-resisting alloys produced by Hadfields, Ltd., are described. The composition of the alloys ranged from about 10 to 30 per cent. Cr and 7 to 40 per cent. Ni, with an iron content of 50 to 70 per cent. The Era heat-resisting steel, which is the alloy more particularly dealt with, does not scale at high temperatures, and its tensile properties are as follows at the temperatures shown:

Maximum stress (tons per sq. in.)	.	58.5	31	24.6	19
At temperatures (°C.)	.	Normal	700	800	900

Numerous applications of the alloy are illustrated and described.

Steel at High Superheat Temperatures. A. McCance. (Heat Treating and Forging, 1927, Vol. 13, Dec., pp. 505-508, 514). The properties of steels and iron alloys at temperatures up to about 600° C. are discussed, this range covering the temperatures at present in use, or likely to be used shortly, in boilers and engines working at high pressures with superheat. "Creep" is described, and an explanation of its occurrence and the importance of the "limiting creep stress" at higher temperatures is given. In this connection the rough parallel between the breaking strengths and melting points of pure materials is pointed out; similar correspondence would be expected with the "self-annealing" temperature at which the hardening effect of strain disappears, this being approximately the same fraction of the absolute melting point for all the commoner metals. Their limiting creep

stresses should therefore also be higher, and this has been found to be the case. Sykes' molybdenum alloy with 15.5 per cent. of iron, when quenched in water from 1525° C., develops a secondary hardness on tempering which is maintained even after tempering for long periods at 775° C. This is so far the highest temperature at which any material has been able to resist the softening action of temperature.

Acid-Resisting Metals and Alloys. W. Rohn. (*Korrosion und Metallschutz*, 1928, Vol. 4, Mar., pp. 49-53). The author discusses the meaning of "acid resistance" and remarks that no commercial metal is proof against all corrosive media; in testing materials, therefore, it is necessary to know the conditions of usage before the tests can be designed to prove or disprove the suitability of the material for the use to which it will be put. He reproduces the Periodic Table, each element being marked with signs to indicate its resistance to attack by various acids, including acids present in foodstuffs, and whether it is of use in making acid-resisting alloys. Finally, the author discusses the acid-resisting properties of various alloys, in particular steel alloys, illustrating his remarks with photographs of test-pieces after attack by various acids. Water-bath rings of various alloys, each of which was polished on half its surface and the other half roughened, demonstrate the influence of the character of the surface itself on the acid-resisting properties of the metal.

Nickel Alloys and Corrosion. A. Portevin. (*Revue de Métallurgie, Mémoires*, 1927, Vol. 24, Dec., pp. 697-714). In Part I. the author discusses the difficulty of making corrosion tests which shall be truly comparable, either to the conditions in practice or even amongst themselves. In Part II. he enumerates the corrosion-resisting properties of a large number of nickel alloys, many of which are nickel steels or iron-nickel alloys.

Metal Corrosion and Metal Protection. W. H. Creutzfeldt. (*Archiv für das Eisenhüttenwesen*, 1927, No. 6, Vol. 1, Dec., pp. 427-435). The action of oxygen in producing corrosion is quite shortly explained and the various well-known methods of coating iron, for its protection against rust, are enumerated and described. The effect of alloying iron with copper, chromium, nickel, &c., to produce a non-rusting iron is also discussed.

The Structure of High-Chromium Steel Alloys. P. Schoenmaker. (Communication from the Metallographic Laboratory, Artillery Factory, Hembrug, Holland: *Stahl und Eisen*, 1928, Vol. 48, May 3, pp. 591-593). A discussion of the effect of various heat treatments and cooling on the structure and properties of chromium steel alloys containing 16.5 per cent. chromium. Experiments made by the author confirm the observations of previous investigators.

Contribution to the Knowledge of the Iron-Chromium Phase Diagram. P. Oberhoffer and H. Esser. (Stahl und Eisen, 1927, Vol. 47, Dec. 1, pp. 2021-2031). Investigations carried out by means of X-ray photographs on iron-chromium alloys led to the conclusion that the two components, iron and chromium, form with each other an interrupted series of mixed crystals. The investigations tend to show that the gamma-phase of iron in the iron-chromium binary system is a limited one, and this hypothesis is confirmed by thermo-analytical investigations according to the differential method.

The Alloys of Chromium and Iron. (Metallurgist, 1928, Feb. 24, pp. 26-28). The article gives a brief account with comments of the work of Pakulla and Oberhoffer (Berichte, Werkstoffausschuss v.d. Eisenhüttenleute, No. 68, 1925), and Oberhoffer and Esser (see preceding abstract).

On the Structure of the Iron Chromium-Carbon System. A. Westgren, G. Phragmén, and Tr. Negresco. (Paper read before the Iron and Steel Institute, May 1928: this Journal, p. 383).

The Properties and Engineering Uses of Stainless Steel. R. Waddell. (Transactions of the Liverpool Engineering Society, 1926, Vol. 47, pp. 233-267).

Stainless Iron. H. S. Primrose. (Proceedings of the Staffordshire Iron and Steel Institute, 1924-25, Vol. 40, pp. 59-84). An account is given of the manufacture of mild stainless steel, its physical properties, resistance to corrosion, heat resistance, its working and uses.

Systematic View of Stainless Steels. F. R. Palmer. (Iron Age, 1928, Vol. 121, Mar. 15, pp. 729-730). **The A.B.C. of Stainless Steels.** F. R. Palmer. (Iron Trade Review, 1928, Vol. 82, Mar. 15, pp. 680-681). The high-chrome steels are classified into three groups and their properties and applications briefly noted.

Copper-Bearing Steel—Its Resistance to Corrosion. M. Grison and E. Lepage. (Revue de Métallurgie, Mémoires, 1927, Vol. 24, June, pp. 331-336; *abstracts*, Metallurgist, 1927, Nov. 25, p. 172; Journ. I. and S.I., 1927, No. II. p. 622).

Non-Corrosive Copper Steels. (Technique Moderne, 1928, Vol. 20, Feb. 1, p. 146). The properties of Apso steel developed in France are described. It is claimed that this steel is extremely resistant to atmospheric conditions and to sulphuric acid and hydrochloric solutions.

Influence of Copper on Corrosion-Resistance of Steel and Cast Iron. R. T. Rolfe. (Iron and Steel Industry, 1928, Vol. 1, Apr., pp. 205-208;

May, pp. 237-241). The articles contain a large amount of data collected from various sources; the nature of the protection thus shown to be afforded to steel and cast iron by the presence of copper is briefly discussed. Some corrosion tests carried out by the author on a cast iron containing 1.35 per cent. of copper are recorded, but they are not conclusive.

Cast-Iron Resistant to Acid and Alkali Attack. H. G. Haase. (*Stahl und Eisen*, 1927, Vol. 47, Dec. 15, pp. 2112-2117). Experiments were made to determine the influence of carbon, silicon, manganese, phosphorus, sulphur, nickel, and of the skin of the casting on the solubility of cast iron in acids and alkali liquors at various temperatures and concentrations. Tests were first made on cast-iron vessels with silicon ranging from 1 to 12 per cent. The effect of varying percentages of manganese and phosphorus was also studied. Finally, a cast iron with nickel ranging from 0 to 0.85 per cent. was tested. The results are well summarised in the form of diagrams, and the best composition for acid-resisting cast iron is stated to be as follows: Carbon 3.3 to 3.5, silicon 1.3 to 1.4, manganese about 0.75, phosphorus not above 0.2 to 0.3, sulphur not above 0.07, nickel 0.3 to 0.5 per cent. The attacking media used for the tests were sulphuric acid, hydrochloric acid, and nitric acid.

The tests for resistance to alkaline attack showed that the silicon content should be kept as low as possible without the iron becoming white; the silicon content should therefore be about 1.2 to 1.4 per cent. Manganese is not attacked by alkalis, but it has the objectionable property of turning alkalis brown. On this account the manganese should not exceed 0.3 to 0.4 per cent. Phosphorus is readily dissolved by potassium and sodium solutions, especially when warm; moreover, phosphorus is apt to decompose alkaline solutions. Phosphorus should therefore not exceed 0.2 to 0.3 per cent. Sulphur is not attacked by alkalis, and is without influence on their permanency. The heat-resisting quality of the cast vessels requires, however, that the sulphur shall be kept low, and it should not exceed 0.08 as a maximum. A nickel addition of 0.05 up to 1 per cent. is said to have a favourable influence on resistance to alkali attack, and a nickel addition of 0.3 to 0.5 per cent. is therefore recommended.

The presence of a smooth casting skin free from any defect increases the resistance to any chemical attack by 20 to 25 per cent.

Corrosion and Corrosion-Resistant Alloys. (Heat Treating and Forging, 1928, Vol. 14, Feb., pp. 167-171). The article describes the processes of attack by gases and liquids, and the composition of various corrosion-resisting alloyed steels and non-ferrous metals.

Non-Rusting Steels. B. Strauss. (*Zeitschrift für Elektrochemie*, 1927, Vol. 33, Aug., pp. 317-321).

CORROSION OF METALS.

Deterioration of Steels in the Synthesis of Ammonia. J. S. Vanick, W. W. de Sveshnikoff, and J. G. Thompson. (United States Bureau of Standards, 1927, Technologic Paper No. 361). The results are presented of an investigation of the resistance to deterioration of steels for service as primary containers in the synthesis of ammonia at elevated temperatures and high pressures. Practical experience and early experimental work showed that plain carbon forging steels were liable to rapid deterioration. Ten commercial steels were subjected to the working conditions of 500° C., 100 atmospheres pressure, and 8.3 per cent. ammonia. It was found that carbon steels decarburised and fissured readily. Nickel steels were deeply penetrated but showed a high residual strength in spite of parallel longitudinal fissures. Chromium steels deteriorated readily if they were of high carbon content, but were quite resistant when the carbon was low. Tungsten and nickel increased the resistance to deterioration of chromium steel if the latter were of low carbon content. A second test was made upon a series of chromium-vanadium steels, in which the carbon was averaged from 0 to 1.15 per cent., chromium from 0 to 14 per cent., and vanadium from 0 to 0.65 per cent. The results showed that a low carbon content was desirable, and vanadium contributed no perceptible improvement. Chromium in the amount of 2.25 per cent. stopped selective penetration and intergranular fissuring, and limited the depth of penetration. Larger quantities of chromium further improved the resistance, but not in proportion to the increase in chromium content. High chromium and nickel-chromium steels of the stainless type are most resistant, but are difficult to forge or machine. The chief features of the attack of the gases upon the steels were represented by decarburisation; sharp increase in combined nitrogen, principally in the chromium steels; fissuring; porosity in the affected zones; lowered strength and ductility. Evidence that carbon was eliminated during exposure was secured. Decarburisation, fissuring, and the presence of combined nitrogen in some of the steels are accounted for, first, by the presence in the gas mixture and the penetration into the steels of molecular hydrogen; secondly, by the injection of activated hydrogen released from catalysed reactions; thirdly, by the inflation of the crystal lattice by hydrogen "activated" during its infiltration into the steels; fourthly, by the more rapid diffusion of hydrogen as the gas mixture passes through the steel, causing localised enrichment of ammonia which causes the formation of nitrides, which are, in turn, decomposed. Internal decarburisation, and the presence of nitride layers in the chromium steels, in spite of their being in contact with gases which decompose nitrides, would be accounted for in a cyclic reaction which is composed of nitride formation and decomposition.

Corrosion of Metals as Affected by Time and by Cyclic Stress. D. J. McAdam, jun. (American Institute of Mining and Metallurgical

Engineers, 1928, Technical Paper No. 58). In this paper the effect of corrosion that is given chief consideration is its action on the fatigue limit. With the fatigue limit as a criterion an investigation was made of the effect of stressless corrosion, and of corrosion at various cyclic stresses from zero to the corrosion fatigue limit. Each "prior-corrosion fatigue" test consists of two stages, a pitting stage in water, and a fatigue stage in air. Part I. of the paper gives an outline of the investigation, and a description of the material and methods used. Part II. discusses the effect of cyclic stress on the corrosion of chrome-vanadium steel. Graphs show the effect of stressless corrosion, and of corrosion under cyclic stress, on the fatigue limit, and on stress concentration. Parts III., IV., and V. discuss the effect of cyclic stress on corrosion of corrosion-resistant steels, copper, copper-nickel alloys, and aluminium alloys. Part VI. discusses the influence of electro-chemical and physical properties on the behaviour of alloys under corrosion and cyclic stress. Among the subjects discussed in the foregoing parts are corrosion fatigue limit, pitting limit, notching limit, notch-depth limitation, and effect of thickness of section. Part VII. discusses the effect of time and number of cycles on corrosion pitting. Depth of pitting is found to depend only on cyclic stress, provided the number of cycles exceeds a critical value which varies with the time per cycle (cycle frequency). Relation between time per cycle, critical number of cycles, and critical total time is briefly discussed.

A Thermodynamic Study of Fundamental Corrosion Reactions.

W. J. Sweeney. (Paper read before the American Electrochemical Society, Apr. 1928). The fundamental corrosion reactions of iron in the absence of oxygen and the iron-ferrous ion-hydrogen ion-hydrogen equilibrium are discussed from an electromotive and free energy standpoint. From a critical survey of the literature on the solubility of iron and of ferrous hydroxide, a solubility product of $10^{-18.8}$ and a provisional value of $-120,920$ cal. for the free energy of formation from the elements of ferrous hydroxide are obtained. With this value the conclusion is drawn that there is a small free energy decrease for the attack of iron by water to form ferrous hydroxide and hydrogen even in the absence of oxygen. The interdependence of the iron, ferrous ion, hydrogen ion, hydrogen equilibrium, and the ferrous hydroxide equilibrium is also pointed out.

Corrosion and Protection of Metals. W. H. Creutzfeldt. (Stahl und Eisen, 1928, Vol. 48, Feb. 23, pp. 228-229). Four main groups of corrosion characteristics are distinguishable: (1) Direct oxidation at high temperatures; (2) corrosion due to atmospheric action; (3) corrosion in natural waters; (4) corrosion in strongly attacking liquids. Four methods of protection against such corrosion and their application are very shortly outlined: (a) Reduction of corrosion by production or selection of suitable metals and alloys, or by suitable heat

treatment; (b) coating the surfaces with paint, oxides, or metals; (c) elimination of the attacking media in the surrounding air or liquid; (d) control of electrolytic action by electric counter currents.

The Corrosion of Metals. W. M. Guertler. (Transactions of the American Society for Steel Treating, 1928, Vol. 13, May, pp. 759-794). The author discusses the problem of corrosion from the metallurgical viewpoint. From his study of the subject he derives many valuable and practical conclusions as to what may and may not be expected as to the corrosion-resisting qualities of different metals and alloys. According to the author, the basis of all commercial acid-resisting alloys necessarily must be the group of elements, iron, nickel, and copper. The various elements that might be added to improve the mechanical, electrical, and other properties should be taken up by them in solid solution. The one-phase homogeneous structure characterises all of the highly resistant alloys, no matter how complicated the composition; that is, every crystal contains all the metals present in the same amount and in solid solution. The author also explains that no one permanently durable alloy can ever be developed which will be resistant to all acids.

Passivity and Corrosion. U. R. Evans. (Metal Industry, 1928, Vol. 32, Mar. 2, pp. 231-232). The author explains that very thin films of iron oxide are the cause of the passivity of iron; thicker films give rise to temper colours. He then discusses the corrosion of a steel bar partly immersed in a salt solution, and describes the part played by the iron oxide films in the corrosion process; the effect of oxygen is to produce passivity at those parts which it reaches directly, and corrosion at the parts not reached directly. Electrolysis, of course, also forms part of the process of corrosion.

Some Recent Work on the Corrosion of Metals. U. R. Evans. (Transactions of the Liverpool Engineering Society, 1926, Vol. 47, pp. 207-232).

On the Passivity of Iron "Mirrors." G. Patscheke. (Korrosion und Metallschutz, 1927, Vol. 3, Dec., pp. 268-270). The vapour of iron carbonyl was heated in evacuated glass vessels; the decomposition of the gas produced "mirror" deposits of metallic iron on the sides of the vessel. The passivity of these mirrors was compared with that of similar iron mirrors which were allowed to come in contact with air for a short period. The "aired" mirrors behaved like normal iron; they were soluble in nitric acid of sp. gr. 1.20, but were rendered passive by strong nitric acid (sp. gr. 1.42). The vacuum mirrors were, however, soluble in the strong acid, except when they were very thick, when a passive residue was left. It was shown that for passivity to occur, a little free oxygen must have access to the iron; re-evacuation

was not enough to reconvert the mirror to the active state, but heating in addition was necessary. Polarised light was employed to study these surface phenomena further, and all the evidence obtained supported the hypothesis that the passivity of iron is due to the formation of a protective coating of iron oxide.

Modern Views Regarding Corrosion. (Heat Treating and Forging, 1928, Vol. 14, Mar., pp. 270-273). Corrosion and its prevention by chromium plating are discussed. The electro-deposition of chromium and the conditions, baths, &c., required, are dealt with.

An Investigation of the Corrosion of Metals with a Thermobalance. K. Inamura. (Science Reports of the Tôhoku Imperial University, Sendai, 1927, Vol. 16, pp. 987-997). The author has studied the corrosion phenomena of iron by means of a thermo-balance, the results showing only the changes in the weight of the specimens in the very early state of corrosion. The specimen used was a commercial iron, and the corroding solutions consisted of the following reagents of various concentrations: Water, sodium chloride, sodium carbonate, sodium bicarbonate, sodium nitrate, sodium sulphate, and potassium hydroxide. The experiments were carried out at 45° C. In these solutions the iron was corroded with the formation of flocculent and easily detachable ferric hydroxide and decreased in weight continuously. In the cases of sodium carbonate and bicarbonate solutions a gelatinous corrosion product formed on the metal surfaces and could not be detached easily, and the weight of the sample was increased continuously. Owing to the formation of hydrogen gas bubbles on the metal surface, continuous measurement could not be carried out in acid solutions.

A Study of the Resistance of Over-Stressed Wrought Irons and Carbon Steels to Salt-Water Corrosion. J. Newton Friend. (Paper read before the Iron and Steel Institute, May 1928: this Journal, p. 639).

The Action of Water, Air, Oxygen, and Carbon Dioxide on the Corrosion of Iron. K. Inamura. (Science Reports of the Tôhoku Imperial University, 1927, Vol. 16, pp. 979-986). The work described was done to determine the essential factors of corrosion. The action of distilled water, of city water, and of sodium chloride solution upon Armco iron was first studied, and it was found that in the absence of air the waters appear to have no appreciable action upon the iron, and even though it contains sodium chloride, pure water free from oxygen and carbon dioxide has no action. In the next series of experiments a sample of iron was kept in a glass flask containing pure water, and the action of air, oxygen, and carbon dioxide was studied. It was shown that the action of carbon dioxide was weaker than that

of oxygen, while carbon dioxide accelerated the rate of corrosion by oxygen, though not to a very great extent.

Corrosion of Boiler, Water, and Steam Tubes. Schulz. (Fuel Economist, 1927, Vol. 3, Dec., pp. 143-146). An abridged translation of a paper which appeared in *Die Wärme*, Oct. 17, 1927, pp. 689-694.

Corrosion by Liquid Fuels. E. K. O. Schmidt. (Korrosion und Metallschutz, 1927, Vol. 3, Dec., pp. 270-274; Metal Industry, 1928, Vol. 32, Feb. 17, pp. 184-185). While the investigation was principally concerned with non-ferrous metals, steel was also tested. The specimens were subjected to the action of the various fuels for ten months; in one set of tests the specimens were completely submerged, in another set the test-pieces were only three-quarters submerged. In the former tests, benzol and petrol were without action; a benzol-alcohol (50 : 50) mixture caused a fair number of rust spots and some sediment; a benzol-alcohol (70 : 30) mixture produced a heavy coating of rust and a rust-brown sediment. In the latter series of tests, benzol was again without action, but petrol attacked the upper part of the specimen slightly, and both the benzol-alcohol mixtures gave rise to a heavier attack on the upper part than on the lower, with a heavy sediment.

Excessive Corrosion of Galvanised Mild Steel Cisterns. H. F. Richards. (Iron and Steel Industry, 1928, Vol. 1, Mar., pp. 183-184). The cisterns had been used as cold water reservoirs for the hot water systems in dwelling houses, and after eighteen months' service became useless owing to perforation of the bottoms. It was found that the presence of chlorides and free carbon dioxide in the water was the main trouble, and that the corrosion had been accelerated by the temperature of the water rising somewhat owing to the cisterns being too close to the hot tank.

Effect of Sulphur in Gasoline on Wrist-Pin Corrosion in Automobiles. S. H. Diggs. (Industrial and Engineering Chemistry, 1928, Vol. 20, Jan., pp. 16-17). Experiments were carried out to determine the cause of wrist-pin corrosion which had been noted by several automobile manufacturers. A Jordan engine was run for 1 hr. and allowed to stand idle for the same period. All work was done when the temperature was below freezing. Each test represented from 60 to 75 hrs. running time. The results showed that when a gasoline containing 0.040 per cent. sulphur was used there was no corrosion of wrist-pins, &c., and that the water condensed in the crankcase contained no free acid, but did contain some ferrous sulphate. When using a gasoline containing 0.151 per cent. of sulphur the corrosion was very appreciable and the water in the crankcase contained free sulphuric acid in small quantities. When using a gasoline with 0.458 per cent. of sulphur the corrosion was very serious and the crankcase water was quite acid.

Corrosion in the Refrigerating Industry. J. K. Roberts, H. O. Forrest, and R. P. Russell. (Refrigerating Engineer, 1927, Vol. 14, Dec., pp. 173-182, 187). The final report of the Corrosion Committee of the American Society of Refrigerating Engineers is presented. The corrosion of iron, steel, and galvanised steel in brine systems may be greatly reduced by the addition of sodium dichromate to the brine. The use of disodium phosphate as a corrosion retarder is noted, and a comparison is made of the dichromate and phosphate treatments.

The Chemical Destruction of Cast Irons. W. Denecke. (Die Giesserei, 1928, Vol. 15, Apr. 6, pp. 307-312).

The Spongy Disease of Cast Iron. R. Stumper. (Korrosion und Metallschutz, 1927, Vol. 3, Dec., pp. 265-268; *abstract*, The Graphitisation of Cast Iron), Iron and Steel Industry, 1928, Vol. 1, May, pp. 247-249). The phenomenon of spongy disease, or graphitic corrosion, of cast iron, its mechanism and effects, and the conditions necessary for its occurrence are discussed. The author then describes an investigation recently carried out by him. Some grey cast-iron pipes which had lain in the ground for thirty years, and carried drinking water, were examined; they were of 60 mm. internal diam. with walls 7 mm. thick. While the outsides showed no appreciable corrosion, the insides were heavily covered with a nodular coating of rust, which in places was 25 mm. thick. Under the rust coating graphitic corrosion was found in every case. Analyses of the remaining sound metal, the rusted material, and the water, are given. The structure of the original metal and the manner of corrosion are discussed.

The Effect of Impurities on the Corrosion of Metals. C. J. Smithells. (World Power, 1928, Vol. 9, Feb., pp. 85-93). The effect of impurities in metals is discussed in relation to the modern electrochemical theory of corrosion.

The Coating on Iron Electrodes in Corrosion Experiments. W. v.-W. Scholten. (Korrosion und Metallschutz, 1928, Vol. 4, Apr., pp. 73-74). The experiments described were designed to determine whether ferrous and ferric hydroxides could form solid solutions. Potentiometric titrations of an acid ferrous sulphate solution with a hypochlorite solution, and of a strongly alkaline hypochlorite solution with an acid ferrous sulphate solution, were carried out. In the acid solution the potential values indicated a smooth change from ferrous sulphate to ferric sulphate; in the alkaline solution, the potential values pointed to the presence of a solid solution of $\text{Fe}(\text{OH})_2$ in $\text{Fe}(\text{OH})_3$.

The Corrosion of Iron and its Anodic Polarisation. R. A. Dengg and H. J. Donker. (Korrosion und Metallschutz, 1927, Vol. 3, Nov., pp. 241-246). The results of tests to determine the relationship

between the corrosion of the iron and steel samples and the degree of their anodic polarisation are recorded and discussed.

Tinplate and the Electrochemical Series. E. F. Kohman and N. H. Sanborn. (*Industrial and Engineering Chemistry*, 1928, Jan., Vol. 20, pp. 76-79). Experiments were conducted to determine the mechanism of the corrosion of tin and iron, both when in contact and when not in contact, in fruits, and the relation of the results to the electrochemical theory of corrosion. It was found that in a number of fruits tin is anodic to iron. Although not all fruits were studied, the data indicate that this is a rather general condition in canned fruits. Many of the facts which did not conform to the older idea that tin is cathodic to iron are readily explained in accordance with these new findings. Electrical measurements were likewise made, and they bear out the results of the corrosion tests that tin is anodic to iron. The nature of corrosion in fruits is distinctly different from that in solutions of the fruit acids. The results are in harmony with commercial experience.

The Corrosion of Metals as an Electrochemical Problem. A. Thiel. (*Zeitschrift für Elektrochemie*, 1927, Vol. 33, Sept., pp. 370-386). The author reports new experiments which are based on the theory that corrosion is strictly an electrochemical problem.

Electrolysis Testing. B. McCollum and K. H. Logan. (United States Bureau of Standards, 1927, Technologic Paper No. 355). The Bureau of Standards has carried out considerable work on methods of electrolysis testing. As a result a new method has been developed which yields much more accurate and detailed information concerning localised electrolysis conditions than it is practicable to secure otherwise. This method consists in measuring the intensity of discharge of current from a portion of a pipe line, which factor is the one most directly related to the rate of corrosion. In the present report the various electrolysis tests are discussed in the light of the most recent data concerning them. The older methods of determining general electrolysis conditions are first dealt with, and then a detailed description of the new apparatus and methods for studying local conditions is given. This is followed by a description of tests for the determination of track conditions, and a discussion of the interpretation of electrolysis data.

LABORATORY APPARATUS AND EQUIPMENT.

A High-Frequency Vacuum Furnace of Simple Construction for Laboratory Purposes. E. W. Fell. (*Archiv für das Eisenhüttenwesen*, 1928, Vol. 1, Apr., pp. 659-661). The crucible of the furnace, which takes a charge of 1 to 1½ kg., rests upon a 20 mm. thick glass plate and

is completely enclosed in a glass bell which is connected to a high-vacuum pump. The joint between the bell and the plate is rendered air-tight by grinding the glass surfaces and placing a rubber ring between them. The body of the furnace is water-cooled. A vertical tube passes through an air-tight plug at the top of the bell, and at the upper end of the tube a small metal drum divided into 6 chambers is attached. This drum is enclosed in a glass casing and can be revolved from outside by a small handle. Any required additions are placed in one or other of the chambers and by turning the drum are dropped through the tube into the furnace. Gaseous additions can be made through a three-way tap in the pipe connection leading to the vacuum pump. The furnace is operated by a Lorenz high-frequency set, generating 3.6 kw. at 8000 cycles. Charges of 1 to $1\frac{1}{2}$ kg. of great purity can be melted under vacuum of 0.5 to 3 mm. mercury column without difficulty. Some data of melts of electrolytic iron, nickel, and copper are given.

Type of Electric Furnace for the Microscope. G. Friedel. (*Revue d'Optique*, 1927, Vol. 6, Jan., pp. 34-47). The author describes a small electric furnace capable of being carried on the stage of a microscope and large enough to contain the specimen and the thermometer by which the temperature is read. The temperature may be raised to and held at any point up to about 400° C.; large magnifications are not, however, possible with this apparatus in use.

Kaiser-Wilhelm Institute for Iron Research at Düsseldorf. F. Körber. (*Stahl und Eisen*, 1927, Vol. 47, Oct. 20, pp. 1737-1743). An illustrated description is given of the Iron Research Institute founded at Düsseldorf in 1917. Plans of the floors showing the various departments are given, along with photographs of the different laboratories.

EXHIBITIONS.

Exhibition of Materials of Construction, Berlin, 1927. (Iron and Steel Section.) (*Stahl und Eisen*, 1927, Vol. 47, Oct. 20, pp. 1743-1778; Dec. 22, pp. 2149-2189). A descriptive report is given of the Exhibition of Materials of Construction which contained a number of exhibits showing recent advances in metallurgical science and practice. A series of lectures on subjects of metallurgical interest was organised in connection with the Exhibition, abstracts of all these lectures being given in Part II. of the Report.

Cast Iron at the Materials Exhibition, Berlin. Lischka. (*Die Giesserei*, 1928, Vol. 15, Jan. 13, pp. 33-39). The author describes and discusses the cast-iron section of the Materials Exhibition.

CHEMICAL ANALYSIS.

ANALYSIS OF IRON AND STEEL.

Note on the Determination of Oxides in Steel. F. Willems. (Archiv für das Eisenhüttenwesen, 1928, Vol. 1, Apr., pp. 655-658). A series of investigations was undertaken with the object of separating the oxide constituents in commercial steel by bringing them into a state of solution, iodine being the solvent employed, and then by treating analytically the whole of the residues. It was not found possible, however, to determine the total oxides nor the manganese oxide alone by the use of iodine solutions according to the ordinary methods. A new iodine method is described in which the cuttings were treated with anhydrous alcoholic iodine solution out of contact with air. This method gave good comparative results for manganese oxide, and simultaneously enabled the silica and alumina to be determined.

Determination of Minute Amounts of Cobalt in Steel. W. J. Agnew. (Analyst, 1928, Vol. 53, Jan., pp. 31-32). The steel is dissolved in *aqua regia*, the solution freed from nitric acid, and the iron (and chromium) separated by zinc oxide emulsion. Copper is removed with sulphuretted hydrogen and the cobalt precipitated with α -nitroso- β -naphthol. The precipitate is filtered off, washed, and ignited; the residue is dissolved in a few drops of hot strong hydrochloric acid, and the solution diluted and filtered into a Nessler tube. 10 c.c. of ammonia (1:1) and 5 c.c. of a 0.1 per cent. solution of potassium ferricyanide are added; the deep red colour is matched by a standard cobalt solution in a second tube into which similar amounts of reagents have been added. The sensitiveness of the test is 1 part in 500,000.

Manganese in Steel and Pig Iron. L. E. Stout and G. C. Whitaker. (Industrial and Engineering Chemistry, 1928, Vol. 20, Feb., pp. 210-212). The authors present a method for the preparation of standard vanadyl sulphate solution from ammonium metavanadate; they describe a vanadate method for the determination of manganese in steels and pig iron, and show the effect of silver sulphate concentration on the rate of oxidation of manganese from manganous nitrate to permanganic acid.

Estimation of Manganese in Steels or Alloys containing large Amounts of Chromium or Cobalt. E. Rousseau. (Chimie et Industrie, 1927, Vol. 18, Nov., pp. 772-780). The author describes a method of

separating manganese from large quantities of chromium and/or cobalt by precipitating the manganese with ammonium persulphate in an ammoniacal solution containing an excess of ammonium salts, and reports the results of tests made to check the accuracy of the method.

Concerning the Separation of Iron, Chromium, Nickel, Manganese, Tungsten, and Silicon. P. Wenger and E. Rogovine. (*Helvetica Chimica Acta*, 1927, Vol. 10, Mar. 15, pp. 242-244). For the separation of these elements when present together in an alloy, the authors vary the mode of attack according to the nature of the sample. If the metal can be reduced to fine chips (turnings), they take 0.5 gm., attack with sodium peroxide, dissolve in water, add hydrogen peroxide to decompose the permanganate formed, and filter off manganese dioxide and nickel and iron oxides; the latter are dissolved in hydrochloric acid and separated by the basic acetate method. The alkaline filtrate is acidified with hydrochloric acid, evaporated dry and the residue treated with dilute acid; the silica and tungstic acid are filtered off, the chromium remaining in solution as chromate. If the metal is in the form of thin wires, it is attacked with *aqua regia*; the insoluble is filtered off, and washed and fused with sodium carbonate. The melt is dissolved, and the solution acidified and added to the *aqua regia* liquor. As before, the silica and tungstic acid are rendered insoluble by evaporation to dryness, &c. The solution is made alkaline with caustic soda and oxidised with bromine, which precipitates iron, nickel, and manganese. The chromate remains in solution.

Colorimetric Determination of Molybdenum in Steels. J. Kassler. (*Chemiker-Zeitung*, 1927, Vol. 51, Dec. 10, pp. 953-954). The method is based on the colour reaction of the molybdate ion with potassium thiocyanate and stannous chloride in an acid solution.

A High Vacuum Induction Furnace and its Application to the Study of Gases in Metals. P. H. Brace and N. A. Ziegler. (*American Institute of Mining and Metallurgical Engineers*, 1928, Technical Publication No. 59). The construction and operation of a high vacuum induction furnace and gas analysis system are described, by means of which quantities of steel up to approximately 13 lb. may be maintained at temperatures above 1600° C. in a vacuum better than 0.001 mm. mercury, and the amount and nature of the gases evolved from the metal determined quantitatively. Specially prepared refractories are used and preheated to reduce errors due to gases liberated from them. The analysis system is entirely of glass, and mercury pumps are used for handling the gases. Separation of the gaseous mixtures into their components is accomplished by selective condensation, and the respective quantities are determined volumetrically. Experimental data on gases from Armco ingot iron and electrolytic iron are given, and

indicate that the two metals behave very differently with respect to gas absorption.

Gases in Metals. III.—The Determination of Nitrogen in Metals by Fusion in Vacuum. L. Jordan and J. R. Eckman. (United States Bureau of Standards, 1927, Scientific Paper No. 563). A method has been developed for the determination of nitrogen in the gases evolved from metals fused in a vacuum. As in a previously described method for the determination of oxygen and hydrogen by vacuum fusion, the metal sample is melted in a graphite crucible in a high-frequency vacuum furnace. The nitrogen, together with the other gases evolved except the noble gases, is "absorbed" in calcium vapour. The calcium nitride thus formed is dissolved in dilute hydrochloric acid with the formation of an ammonium salt, and the resulting ammonia is determined by distillation into a standard acid. The efficiency of the determination of nitrogen by "absorption" in calcium vapour was determined by tests with known gas mixtures. The complete vacuum-fusion procedure was applied to the analysis of several synthetic nitrides (silicon, aluminium, titanium, zirconium, chromium, vanadium) and a few irons and steels. The results obtained were compared with the nitrogen values given by the usual acid-solution method for nitrogen in metals. The fusion method has a precision equal to that of the solution method, and gives higher values for nitrogen than the solution method in the analysis of nitrides of silicon, titanium, and vanadium, and in certain iron and steel samples. The fusion method should determine also any "uncombined" nitrogen in a metal.

An Improved Rapid Method for the Determination of Gases in Metals, particularly of Oxygen in Steel. W. Hessenbruch and P. Oberhoffer. (Archiv für das Eisenhüttenwesen, 1928, Vol. 1, Mar., pp. 583-603). Particular care was spent in the construction of a suitable apparatus for determining oxygen, hydrogen, and nitrogen by the hot-extraction method; a special quality of porcelain was developed and a furnace was constructed for extraction at 1600° C. The subsidiary reactions during hot extraction were studied, and the reduction of the oxides and of the material of which the boat was formed was also carefully investigated. Results are tabulated of numerous analyses for oxygen and hydrogen in a number of commercial steels, special steels, and pig iron, and these are compared with results by older methods. The differences are very considerable in some instances. An excellent bibliography accompanies the article.

ANALYSIS OF ORES.

Rapid Method for Determining Sulphur in Iron Ores. C. C. Hawes. (Mining and Metallurgy, Nov. 1927, pp. 462-464). In the method

described $\frac{1}{2}$ gram. of iron ore is intimately mixed with 2.50 gram. of iron powder, and heated out of contact with air in a nickel crucible. The iron sulphide produced yields hydrogen sulphide gas on treatment with hydrochloric acid. Subsequent titration with iodine gives quick and accurate results.

Rapid Analysis in Siderurgy. J. Navarro. (*Chimie et Industrie*, 1927, Vol. 18, Dec., pp. 993-996). Rapid methods of analysis are described for the estimation of carbon, manganese, silicon, sulphur, phosphorus, and oxygen.

ANALYSIS OF FUEL.

Pure Coal as a Basis for Classification. F. V. Tideswell and R. V. Wheeler. (*American Institute of Mining and Metallurgical Engineers*, 1928, Technical Paper 104). The object of this paper is to examine one important source of error in ultimate analysis, that due to the occurrence in coal of inorganic material, and to emphasise the need for the quantitative measurements (of carbon more particularly) on coals to be rendered independent of their contents of such material. The magnitude of the errors involved by the presence of inorganic materials is greater than is generally realised. By calculation to the basis of the "pure coal"—that is to say, the coal free from the associated inorganic matter, which is greater in amount than the derived ash—the errors can be reduced considerably. This applies particularly to the shaley and pyritic constituents. Calcium carbonate cannot so readily be corrected for, and it is advisable (and practicable) to free the sample from carbonate. The corrections indicated in the paper are not absolute, and though their use minimises the errors involved in the analysis of impure coal (and is therefore always advisable), it is desirable, when exact knowledge of the composition of a coal is required, to reduce the magnitude of the corrections to be applied by working on as pure a sample as can be obtained.

Total Carbon in Coal. A. R. Carr and A. M. Rente. (*Industrial and Engineering Chemistry*, 1928, Vol. 20, May, pp. 548-549). A method is described for the determination of the total carbon in coal. The coal sample is exploded and its heating value is determined in a Mahler type of bomb. The products of combustion are expanded into a rubber balloon inside a large bottle filled with water and the displaced water is weighed. The pressure and temperature of the gas in the balloon are recorded. The carbon dioxide content is estimated by means of a caustic pipette and the total carbon in the sample is computed. This method requires no special apparatus other than that in general use for coal calorimetry and gas analysis.

The Use of the Bomb for the Determination of Carbon and Hydrogen. J. W. Whitaker. (Fuel, 1928, Vol. 7, Feb., pp. 63-65). The method of determining carbon and hydrogen in a sample of coal by oxidation under pressure may be carried out readily by the introduction of oxygen into the bomb. Goutal (Paris) has designed a special form of bomb in which the determination under oxygen pressure can easily be made, and the method is fully described.

A Volumetric Method for the Determination of the Ash Content and the Calorific Value of Coal. P. N. Lategan. (Fuel, 1927, Vol. 6, Oct., pp. 447-448).

The Determination of Volatile Matter in Coke. F. J. Eaton and S. Pexton. (Journal of the Chemical Society, 1928, May, pp. 1215-1217). The method described is carried out in an electric furnace. The air is displaced by an atmosphere of nitrogen in order to prevent oxidation of the sample, and by using a platinum crucible to contain the sample rapid heat transfer is attained so that the temperature of the sample is indicated by the thermocouple in contact with the bottom of the crucible more accurately than it would be if a porcelain crucible were used.

The Estimation of Nitrogen in Petroleum and Bitumens. E. J. Poth, W. D. Armstrong, C. C. Cogburn, and J. R. Bailey. (Industrial and Engineering Chemistry, 1928, Vol. 20, Jan., pp. 83-85). Suggestions of procedure are offered for the estimation of nitrogen in petroleum products and bitumens by the Dumas and Kjeldahl methods. The analytical data presented make it doubtful whether any Californian petroleum contains as much as 1 per cent. of nitrogen or any Texas Gulf Coastal oil as much as 0.1 per cent. of nitrogen. Proof is furnished that (1) the nitrogen compounds in crude petroleum are not always in basic form, and (2) chemical changes occur in the nitrogen compounds on distillation of petroleum.

Pyrometer Tubes and Gas Sampling Tubes for Gas Analysis Determinations. W. Funk. (Feuerfest, 1928, Vol. 4, Jan., pp. 1-3). The chemical and physical properties of the refractory tubes used for pyrometers and for withdrawing gas samples for gas analysis, to enable them to withstand the various adverse conditions encountered in service, are described and discussed.

NOTICES OF RECENT BOOKS PRESENTED TO THE LIBRARY.

"Chemical Engineering and Chemical Catalogue." Fourth edition. A Catalogue of Heavy and Fine Chemicals, Raw Material, Machinery, Plant, and Equipment applicable to Production Industries, standardised, condensed, and cross-indexed. Compiled with the co-operation of leading British manufacturers. Editor, D. M. Newitt. 4to, pp. 380. London: Leonard Hill. (Price 10s. 6d.) (Presented by Publishers.)

This catalogue is designed as a standard text-book of reference for chemical consulting and contracting engineers, works' managers, and others charged with the specification and purchase of the plant, equipment, and material utilised in the manufacture mainly of consumable products.

"Engineer's Year Book of Formulæ, Rules, Tables, Data, and Memoranda for 1928." A Compendium of the Modern Practice of Civil, Mechanical, Electrical, Marine, Gas, Aero, Mine, and Metallurgical Engineering. Compiled and edited by H. R. Kempe and W. Hanneford Smith. 8vo, pp. lxxxi + 3169. Illustrated. London, 1928: Crosby, Lockwood & Son. (Price 30s.) (Presented by the Editors.)

This valuable work of reference, which is now in its 35th year of publication, has again appeared in a revised and somewhat enlarged form. The usual general revision has been thoroughly carried out by the editors-in-chief, and the numerous associate editors and contributors have subjected their respective sections to a competent revision. With the co-operation of so many distinguished specialists, whose names are given in the list in the opening pages, this work of reference maintains its reputation as a unique authority, the value of which is universally recognised.

HATFIELD, W. H. *"Cast Iron in the Light of Recent Research."* Third edition, revised and enlarged. 8vo, pp. xv + 340, with frontispiece and 210 illustrations, including many photomicrographs. London, 1928: Charles Griffin & Co., Ltd. (Price 16s.)

The appearance of the third edition of this well-known standard work, thoroughly revised, enlarged, and brought up to date, is particularly welcome. The author's aim has been to collect within the compass of a single volume the results of many researches on the nature and properties of cast and malleable cast iron, which are for the most part scattered throughout the pages of the Journals of technical societies and periodicals. Much of the subject-matter, however, is the result of the author's own investigations, and comprises the practical experience of many years. The work begins with a study of the iron-carbon alloys and cast iron from the standpoint of the equilibrium diagram of the iron-carbide system. The succeeding chapters deal with the influence of silicon, phosphorus,

sulphur, manganese, and the rarer elements, and the remainder of the volume is devoted to the consideration of the influences of such factors as the casting temperature, shrinkage, contraction, and heat treatment generally. These accumulated researches must prove of great value to metallurgical students, engineers, and manufacturers.

LOUIS, H. "*The Preparation of Coal for the Market.*" 8vo, pp. xiv + 217. Illustrated. London, 1928: Methuen & Co., Ltd. (Price 10s. 6d.)

This work consists of a short course of lectures by the author at the Heriot-Watt College, Edinburgh, in 1926, which lectures were repeated in the following year at Armstrong College, Newcastle-on-Tyne. The object of the lectures was to present to British colliery managers a clear statement on the methods employed by other coal-producers, and to impress upon them the necessity of adopting similar improvements in order to retain our share of the world's coal trade. The principles upon which these methods are based are explained, with indications as to how they may best be applied, and economic results which may fairly be expected from their adoption. With the approaching exhaustion of some of the finest coal seams in Great Britain, and in view of the improvements made in other countries in the preparation of coal, the natural superiority of British coals has largely disappeared and Britain's share of the world's coal trade can only be retained by adopting improved methods.

MINISTRY OF LABOUR: "*Report of an Enquiry into Apprenticeship and Training for the Skilled Occupations in Great Britain and Northern Ireland, 1925-1926. VI.—Engineering, Shipbuilding and Ship-Repairing, and other Metal Industries.*" 8vo, pp. 204. London, 1928: H.M. Stationery Office. (Price 7s. 6d.)

For the purpose of this Report the engineering industry has been divided into thirteen branches—namely, (1) aircraft manufacture; (2) heating and domestic engineering; (3) tramways and omnibus maintenance; (4) constructional engineering; (5) motor engineering; (6) marine engineering; (7) electrical and mechanical engineering; (8) locomotive engineering; (9) textile engineering; (10) agricultural engineering; (11) machine tool manufacture; (12) iron-founding; (13) general engineering. Many firms are engaged in more than one of these branches, and in analysing the returns, the principle adopted has been to allocate to a particular branch the firms whose businesses are concerned exclusively or mainly with that branch. The Report deals entirely with the conditions of apprenticeship and training for the skilled occupations in all the above branches of the engineering industry.

"*Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung zu Düsseldorf.*" Edited by Friedrich Körber. Vol. IX., Parts 1 to 22. 4to, pp. 400, with numerous figures and plates. Düsseldorf, 1927: Verlag Stahleisen, m.b.H.

This valuable publication contains the collected researches on iron and steel and their alloys carried out, during 1927, at the laboratories of the Institute for Iron Research at Düsseldorf. Abstracts of the numerous reports and papers appearing in this volume have already been published in Section II. of the *Journal of the Iron and Steel Institute*, and those wishing to inform themselves more closely as to the contents of the volume under review will find notes of all the papers and reports and the refer-

ences thereto. No metallurgical library can afford to be without this important work of reference, which deals with innumerable problems in the metallurgy of iron and steel.

PAVLOFF, M. "*Abmessungen von Hoch- und Martinöfen.*" Unter Mitwirkung des Verfassers aus dem Russischen übersetzt von F. Dreyer. ("*Der Industrieöfen in Einzeldarstellungen.*" Herausgeber L. Litinsky. Band 111.) 8vo, pp. viii + 148. Illustrated. Leipzig, 1928: Verlag von Otto Spamer. (Price 16 marks.)

The author traces the evolution of the blast-furnace from its earliest form, known as the Stückofen, down to the modern type as we know it to-day. The lines of typical furnaces are shown as developed in the eighteenth and nineteenth centuries in Great Britain, Sweden, Syria, Germany, Russia, and the United States. Methods for the calculation of the dimensions of the various parts of the blast-furnaces are given. The second section of the book gives an historical account of the introduction of the open-hearth furnace. Pierre Martin's original furnace is described, and the part played by W. Siemens in designing and constructing a furnace that would withstand the high temperatures which were necessary for the success of the Martin process is indicated. The design and dimensions of modern open-hearth furnaces are fully dealt with, and illustrated according to whether the scrap process or the ore process is to be used. The book is of undoubted value to metallurgists and furnace constructors.

RAWLINSON, W. "*Modern Foundry Operations and Equipment.*" 8vo, pp. xviii + 312 and 52 plates. London, 1928: Chapman and Hall, Ltd. (Price 18s.)

In recent years there has been manifested, on the part of managers in the engineering industry, a considerably greater interest in foundry work than was formerly the case, due to a greater appreciation of the application of scientific methods in carrying out various foundry operations. The author sets forth in clear language the principles underlying the various foundry operations rather than indulging in a description of the practical and manual details. Consideration is given to the several metals available for the production of iron, steel, and non-ferrous castings, and the main operations are surveyed as regards the melting of the metals, preparation of the sands, moulds and cores, cleaning the castings, and the usual methods followed in the testing of castings.

REDPATH, BROWN & Co., LTD. "*Handbook of Structural Steelwork.*" (1928 edition.) 8vo, pp. x + 546. Illustrated. (Presented by the Company.)

This is an entirely new work and not a reprint of the volume which it supersedes. Full details of the 1920 British Standard sections are presented. The special features of the previous edition are retained in this Handbook. These features include: A very extensive range of compound girders and pillars of various types; dimensions, properties, and safe loads for all sections presented on two facing pages; safe loads on pillars both by the Moncrieff and by the London County Council pillar formulæ and copious explanatory notes. The Handbook is not a trade catalogue and is not on the market for sale, but is distributed by Messrs. Redpath, Brown & Co., Ltd., to architects, engineers, and approved applicants.

SMITHELLS, COLIN J. "*Impurities in Metals; their Influence on Structure and Properties.*" 8vo, pp. 157, with 166 figures and micrographs. London, 1928: Chapman and Hall, Ltd. (Price 18s.)

The book is an important contribution to the study of the internal structure of materials. Until quite recently, little information was available respecting the effect of small quantities of foreign substances on the various properties of metals and alloys. Attention has lately been increasingly directed to this phase of metallurgy, and numerous instances are now on record in which small quantities of minor constituents have been found to exert an important influence on the properties of metals or alloys. A few metals have been prepared in a spectroscopically pure state, and the author shows that a comparison of the behaviour of such metals with that of metals ordinarily containing small percentages of impurities may aid in the solution of some of the fundamental problems of metallurgy. Although there is no reason to distinguish between substances which may be properly classed as impurities and small amounts of elements intentionally added or allowed to remain in the metal, the author has preferred to classify all such foreign substances as metallic, non-metallic, and gaseous, rather than describe them collectively as minor constituents. Treated in this way, the subject becomes a natural development of metallography, and therefore some account of the more recent developments in metallographic technique has been given. The application of X-rays has also become a recognised method in metallographical studies, and a general account of the use of X-rays in studying the structure of metals is contained in the book.

SOCIETY OF CHEMICAL INDUSTRY. "*Reports of the Progress of Applied Chemistry.*" Vol. XII., 1927. 8vo, pp. 742. London: Society of Chemical Industry. (Price 10s. 6d.) (Presented by the Society.)

Contents.—General Plant and Machinery, by A. J. V. Underwood; Fuel, by T. C. Finlayson; Gas, Carbonisation, Tar and Tar Products, by J. E. Davis; Mineral Ores, by A. E. Dunstan; Colouring Matters and Dyes, by C. Hollins; Fibres, Textiles, Cellulose, and Paper, by D. J. Norman; Bleaching, Dyeing, Printing, and Finishing, by A. J. Hall; Acids, Alkalis, Salts, &c., by P. Parrish and F. C. Snelling; Glass, by A. Cousen; Refractories, Ceramics, and Cements, by A. T. Green; Iron and Steel, by C. O. Bannister; Non-Ferrous Metallurgy, by G. A. Guess; Electro-Chemical and Electro-Metallurgical Industries, by H. J. T. Ellingham; Oils, Fats, and Waxes, by H. M. Langton; Paints, Pigments, Varnishes, and Resins, by members of the Oil and Colour Chemists' Association; Indiarubber, by P. Schidrowitz; Leather and Glue, by D. Woodroffe; Soils and Fertilisers, by E. M. Crowther; Sugars, Starches, and Gums, by L. Eynon and J. H. Lane; the Fermentation Industries, by H. L. Hind and F. E. Day; Foods, by F. S. Aumonier and J. King; Sanitation, Water Purification, &c., by F. R. O'Shaughnessy; Fine Chemicals, Medicinal Substances, and Essential Oils, by W. H. Gray and H. Paget; Photographic Materials and Processes, by W. Clark.

WHITAKER, J. W. "*Mine Lighting.*" With an Introduction by W. H. McMillan. 8vo, pp. xvi + 200, with 107 illustrations. London, 1928: Methuen & Co., Ltd. (Price 8s. 6d.)

Lack of appreciation of the fundamental principles of illumination and its relation, more particularly in mining, to the surrounding surfaces may account to a large extent for the fact that the scientific aspect of the

question of mine lighting has hitherto been somewhat neglected. The existing literature, which deals with the general principles of illumination, is beyond the scope of most mining men. On these grounds, this excellent monograph, dealing first with the principles of light and vision in a simple way, and afterwards with the most modern practice in mine lighting, is very welcome. The book is full of useful information from cover to cover, and contains much that is new to the majority of mining men. It would be difficult to discriminate between the various portions of the work, but the treatment of and repeated reference to the question of reflection, and its improvement as one of the best and simplest ways of obtaining better underground lighting, is well worthy of mention.

CROMPTON, R. E. "*Reminiscences.*" 8vo, pp. xv + 238. Illustrated. London, 1928: Constable & Co., Ltd. (Price 14s.)

These are the reminiscences of Colonel R. E. Crompton, C.B., R.E. Colonel Crompton was a veteran of the Crimea, where he served as a midshipman. He was an officer of the Rifle Brigade, with the third battalion of which he served in India, and later became a pioneer of mechanical road traction, first of all in India, where he was attached to the P.O. Department. He was among the first to take up Electrical Engineering in this country, and he commanded the Electrical Engineers Corps in the Boer War. He was also a pioneer motorist and an authority on road engineering, and a prominent member of the R.A.C. The book is an interesting story of a life of exceptional activity and interest.

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Printed in England at THE BALLANTYNE PRESS
SPOTTISWOODE, BALLANTYNE & CO. LTD.
Colchester, London & Eton